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THE DECLINE IN THE STRENGTH OF CATGUT AFTER EXPOSURE TO LIVING TISSUES

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It was largely through the efforts of Philip Syng Physick (1816), the first professor of surgery in the School of Medicine of the University of Pennsylvania, that catgut came into general use. He carried out experiments with a wide variety of suture materials and demonstrated the absorbability of catgut. It remained for Lister (1868), however, to begin experiments on the sterilization of catgut, a study which he continued for forty years.

The main requirements for good surgical catgut have been sterility, strength, suppleness and absorbability. The great bulk of the experimental work on catgut recorded in the medical literature has been concerned with its sterility and the effect of various methods of sterilization on its tensile strength. Suppleness is largely a matter of clinical opinion, but it has also been studied in the laboratory by determining the loss of tensile strength that results from knotting.

The absorbability of catgut was demonstrated by Physick in 1816 by placing catgut in contact with ulcers so that it was exposed to the purulent secretions of the wound until it dissolved. The first studies of its absorbability in animals were made by Porta (1845), who used dogs, horses and sheep for his experiments. He buried catgut in eighty instances and classified his results according to the duration of the experiments. In thirty-three experiments the catgut was absorbed in from one day to three years. Although the period necessary was often long, he concluded that catgut was absorbed more readily than other materials then being used for suture and ligation.

Lister made numerous scholarly contributions to this subject. He was chiefly concerned with the sterilization of catgut, its fate in tissues,

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the effect of infected serum on it, the effect of serum on its tensile strength and, later, the effect of chromicizing on its absorbability.

His studies on its fate in tissues showed that it was not only absorbed but replaced with granulation tissue and ultimately with a band of scar tissue (1868). While he measured the tensile strength of catgut prepared by various methods and determined the effect of serum on the tensile strength, he apparently never studied tensile strength during the process of absorption.

Cumming (1872) tied the carotid artery of a rabbit with heavy phenolized catgut and killed the animal after thirty-three days. He found the strands nearly replaced by fibrous tissue. In 1873 von Fillenbaum reported the use of phenolized catgut in the suture of a wound of the hand. The ends came away in four days with filaments of the buried portions. He ligated the carotid artery of a large dog with catgut and found that after fourteen days the ligature was entirely absorbed except for a few microscopic traces. He believed that catgut was fully absorbed in tissues.

Callender (1874) examined a femoral artery nineteen days after ligation with phenolized catgut and found that the ligature had been absorbed. He also placed a number of samples of catgut in a pocket-shaped wound that had resulted from the removal of a fatty tumor on a patient's back. Both ends of each sample were left outside the wound, and a sample was removed every two or three hours and examined. The experiments were not begun until four days after operation, and the secretions from the wound were ordinary and "at no time fetid." After twenty-four hours of contact with the wound, the specimens were found to be thinned. In from forty to forty-five hours only a thin thread remained, and in from fifty-five to sixty hours all had given way. Distilled water at 98 F. produced scarcely any change in one hundred hours. Bruns (1875) placed ligatures of no. 1 catgut on large vessels in thirteen dogs and examined them after ten, twenty, thirty and forty days. At the end of ten days the catgut in four instances was still present but was narrowed. At the end of twenty days only half a loop could be identified macroscopically; after the thirty and forty day periods only microscopic traces remained, except for a fine thread seen macroscopically in one of the four animals kept forty days. Bruns did the first controlled work on the effect of infection of the wound on catgut.

Eliaschewitsch (1875) found that catgut disappeared in thirty days after it was placed in the tissues of the dog's back. Fine phenolized catgut became attenuated in from five to six days or less. Güterbock (1875) placed catgut in the achilles tendons of white rats and kittens and found it microscopically after fourteen days, when it was no longer visible macroscopically. Murinoff (1875) placed several kinds of catgut

in the horns of the uteri of kittens and dogs. No. 3 catgut (Lister's) was absorbed in from twenty to thirty days, though the knots persisted from twenty-five to seventy days. He noted that the catgut was swollen and weak after seven days. Fleming (1876) studied the microscopic changes in catgut inserted in the backs of dogs and rabbits. He found that the strands were completely invaded with cells in from five to twenty days and that granulation tissue was subsequently formed.

Mayer (1878) made microscopic studies of catgut incubated in serum (changed as often as it grew cloudy) and reported that absorption was incomplete in thirty-two days. In bile from the gallbladder of man catgut persisted over nineteen months with little change. Mayer also studied catgut in urine, in wounds, embedded in the liver and in tendons. In tendons he noted that catgut often became encapsulated before absorption was complete.

Tillmanns (1879), working on the absorption of various foreign bodies, noted that a sample of middle-sized catgut on a necrotic piece of tissue in the peritoneal cavity became unrecognizable in eight days.

Hallwachs (1879) reviewed the work on the absorbability of catgut that had been published up to the time his paper was written and reported the results of experiments on dogs. He reported that Schuchardt (a dissertation published in Berlin, 1872) buried rather fine English catgut under the skin covering the backs of guinea-pigs. After eleven days he found no trace of it under a magnification of 275 diameters. No trace of a ligature placed on a femoral artery could be found after forty-three days. Hallwachs also referred to a dissertation by Reverdin (Berlin, 1874), in which was reported the use of catgut (Lister's middle-sized) in kittens as an abdominal ligature, with no change after one day. After three and one-fourth days heavy catgut placed in the abdomen was intact, but fine catgut could not be found. After nine days catgut was encapsulated by adhesions. After ten days the outer part was found to be undergoing organization. Catgut examined after fifteen days was encapsulated and the outer part weakened. After nineteen days three fine and two thick pieces could not be found. After twenty-nine days two pieces of catgut of medium thickness were found encapsulated. Evidently Reverdin's results were not uniform.

Hallwachs himself placed catgut and silk in the peritoneal cavities of dogs. After six months he found the catgut replaced with well vascularized connective tissue.

Rosenberger (1880) published a series of interesting experiments on the power of animals to absorb foreign organic material. One of his dogs absorbed a kitten's kidney (fixed in absolute alcohol) from the peritoneal cavity in thirty days.

Macewen (1881), who was one of the first to recommend chromicizing catgut, tested its absorbability by using it as a deep suture in

thirty-one instances and noting the date of softening by making traction on the ends. The amount of traction was not stated. The average time of softening was fourteen days, the earliest being nine days and the longest nineteen days. In another series of experiments the strands were left until the ends dropped off, which occurred in from fifteen to twenty-four days, the average being twenty days. In the same year Lister published his method of chromicizing catgut. He found that the new product was not eroded in a human patient in ten days. In thirteen days erosion had begun. Von Lesser (1884) tested heavy phenolized catgut in kittens and frogs in various sites (e. g., the vessels, the trachea and the subsynovial and subperiosteal spaces). In the crural muscles of kittens he found traces of catgut in granulation tissue after eighty-five days. He also made numerous studies in vitro. Thomson (1889) tested phenolized and chromicized catgut in the uteri and the abdominal walls of kittens, cats and dogs. The phenolized catgut was entirely absorbed in seventeen days. The chromic catgut was intact

TABLE 1.—*Results of Booth on Tensile Strength of Catgut*

Method of Preparation	Days in Tissue				
	0	1	2	3	6
Reverdin (plain).....	14 lb. (6.4 Kg.)	13 lb. (5.9 Kg.)	10½ lb. (4.7 Kg.)	8¼ lb. (3.7 Kg.)	5¼ lb. (2.4 Kg.)
Chromicized.....	9½ lb. (4.3 Kg.)	9½ lb. (4.3 Kg.)	9½ lb. (4.3 Kg.)	9 lb. (4.1 Kg.)	8 lb. (3.6 Kg.)

after sixty-four days. Silk, he stated, was mostly absorbed at the end of this period. Monari (1890) performed eighty experiments, lasting from thirteen to thirty-four days, on the muscles, subcutaneous tissues and abdominal cavities of rabbits. In none of the tests was the catgut absorbed. The work was said to have been repeated with dogs.

In 1890 Brunner reviewed the whole subject of catgut from the point of view of its sterilization, its strength before use and its absorption. He included reports on clinical experience with catgut from representative clinics all over Germany. It remained for Booth (1894) to test the effect of implantation in tissues on the tensile strength of catgut. The tests were made with a slow, continuous strain testing machine. The samples were knotted. The implantations were made in the lumbar muscles of dogs six days, three days, two days and one day before the animal was killed and the specimens removed. The results, which the author stated should be considered as relative, are partially presented in table 1. This was the first quantitative demonstration that chromic catgut retained its tensile strength longer than the plain variety.

Hofmeister (1896) tested catgut prepared by his method of sterilization with formaldehyde in the subcutaneous tissues of kittens. He

made both macroscopic and microscopic studies and found that the catgut weakened in sixteen days and broke into bits surrounded by connective tissue in from five to six weeks. Catgut prepared with mercury bichloride underwent similar changes.

Borden in 1897 inserted catgut as a skin suture in a convict. The wound suppurated and opened after four days, at which time the catgut (prepared by boiling one and one-half hours in a 1 : 500 solution of mercury bichloride in alcohol) was found in good condition, with leukocytes only at the edge. In 1898 Thomalla suggested coating catgut with formaldehydized gelatin. He stated that this prolonged absorption, which never occurred in less than from eight to ten days.

In 1899 Minervini reported the results of experiments on the sterility of catgut and the effect on its tensile strength of many processes suggested for its sterilization. These studies particularly emphasized that heat in the presence of moisture reduced the tensile strength of catgut. He investigated the absorption of no. 2 catgut in the peritoneum of dogs and found that traces of the specimens could be found microscopically after one hundred and twenty-five days. Catgut prepared by dry heat, oil of juniper and formaldehyde tended to be absorbed. Catgut prepared with chromic acid and with mercury bichloride tended to become encapsulated. His tests of the tensile strength were made with a weight dynamometer, the strain being increased by 25 Gm. increments. All samples tested were 5 cm. long, and his data represent averages of six determinations.

It was in 1902 that Claudius introduced iodized catgut. He found that as a skin suture it became fully organized, i. e., replaced, in from twelve to sixteen days, which he considered slightly slower than was the case with catgut prepared with phenol and alcohol.

Binney (1904) reported favorable clinical experiences with iodized catgut and stated that it had been found from experiments on rabbits and a few clinical tests that its absorption time corresponded closely with that of plain catgut. He stated further that chromicized catgut could be sterilized by the iodine method.

Miyake (1904) prolonged the absorption time of catgut with an extract of quebracho (an Argentine oak particularly rich in tannic acid). He expressed the belief that ordinary catgut (even up to size 4) keeps its strength only from nine to twelve days. After catgut was soaked for twenty-four hours in 5 per cent solution of this extract it was found to last intact sixty-five days or more in the dog under aseptic conditions but to be absorbed in thirty-two days in a septic wound. It was fully absorbed in from eighty-three to ninety-nine days in clean wounds.

Barling (1905) used iodized catgut as a skin suture and noted absorption in from six to fourteen days, depending on the size employed. Kuhn and Rössler (1908) studied the reaction in the anterior

chamber of the eyes of kittens to iodized and silverized catgut. They tested these and other materials in the skin of man. The samples were removed in eight days. One of the iodized specimens was broken and another thinned in this period, but the majority were less changed.

Ilyin (1908) determined the time of absorption of catgut in different tissues and found absorption to be most rapid in the superficial layers of the skin. Hutchings (1911) conducted tests on no. 2 catgut in guinea-pigs and reported absorption in nine days.

In 1912 Claudius reported a method for simultaneously iodizing and chromicizing catgut by adding 1 per cent potassium bichromate to the iodine and potassium iodide solution used for sterilization. He found that this process did not change the physical characteristics of the catgut, at least not for six months, whereas free chromic acid made it brittle. Two weeks in the combined solution increased the digestion time of no. 2 catgut in 1 per cent pepsin and 1 per cent hydrochloric acid at 37 C. from six to seventeen hours. In animal experiments no. 2 catgut prepared for one week in this solution lasted twice as long as plain dry sterilized or plain iodized catgut. He stated that he had found this to be true in different animal tissues, including the anterior chamber of the eye of the kitten. He stated that catgut prepared this way retained its full strength for five years in tubes.

Callam (1912) made the interesting observation that absorption of catgut in the subcutaneous tissues on the backs of white mice could be slowed by painting the overlying skin with croton oil. The effect could not be demonstrated in guinea-pigs. Berryhill (1913) emphasized the point that the persistence of catgut could be varied by the extent of the chromicizing so that the catgut would last from ten to sixty days in the muscles of the thighs of rabbits. Phillips (1914) implanted catgut prepared by cumene and by the Bartlett process in Belgian hares and small dogs. The absorption time in days is given in table 2. The results of tests of the tensile strength during the periods of absorption were reported in a few cases, but the tests were not complete. This work was published as a preliminary report, but no subsequent report has been found.

Goris and Rolland (1917) studied the rate of absorption of catgut by the rate of invasion by leukocytes. Chromic catgut was sixth most resistant of the nine varieties tested. Iodized catgut was ninth, i. e., the least resistant to the invasion of leukocytes.

In 1929 the entire subject of surgical catgut was reviewed by Bulloch, Lampitt and Bushill. They reported a large amount of original work on the sterilization of catgut, showing that many of the methods proposed were inadequate. They also made extensive studies on the influence of various physical and chemical constants, such as the p_H

of the wash liquors and the number of twists per inch of the catgut ligatures, on the tensile strength of the finished product. They did not study the effect of tissue juices on the tensile strength of the catgut.

Howes (1928) studied the decline in tensile strength of Davis and Geck catgut (sizes 00, 0, 1 and 2; types, plain, ten day chromic and twenty day chromic) implanted in dogs in the wall of the stomach. A standard thread-testing machine was used, which was accurate to within one-half pound. The results were recorded as graphs, tensile strengths being plotted against time. The initial strengths were the average of six determinations. The results were represented by straight lines. Tensile strength reached zero in from three to five days for plain catgut, in from seven and a half to thirteen days for the ten day catgut and in from eighteen to twenty-two and a half days for the twenty day catgut. Studies were also reported on the influence of

TABLE 2.—*Absorption Time of Catgut as Ascertained by Phillips*

Plain			Iodized Chromic		
No.	Tissue	Days	No.	Tissue	Days
00	Human prepuce	7	1	Peritoneum	18
0	Muscle	11	1	Muscle	22
0	Fascia	10	1	Fascia	20
1	Muscle	13	2	Muscle	20
2	Muscle	16	3	Muscle	20
3	Fascia	21			

saline solution, of blood serum, of infected blood serum and of sterile pus on catgut in vitro and on the fate of catgut in infected wounds.

In an interesting series of articles Howes and his co-workers (1929 and 1933) presented the results of studies of the tensile strength of wounds during the course of their healing, of the holding power of sutures in various tissues and of the time of healing of wounds in the stomach sutured with catgut and silk and correlated the results of the studies.

Reil (1928), who has written chiefly on the chemistry of catgut and the chemical reactions that occur in the course of various methods of sterilization, stated that large animals absorb a given amount of catgut faster than small ones. Braun (1929) stated that the fixed cells and leukocytes are more active in the process of absorption than the blood, as shown by experiments in which catgut was placed in the blood stream. Details of the work were not given. Baisch (1930) made a report on the use of copper catgut (developed by von Linden), which he stated remains strong in tissues for eight days and then slowly disappears. He reported a series of five hundred laparotomies and three

hundred vaginal operations in which it had been employed without rupture of the wound.

Mehnert (1930) reported a series of experiments on the persistence of catgut knots in defibrinated human serum. He also introduced catgut in man as a skin suture. Fine no. 000, no. 00 and no. 0 unhardened iodized catgut (Pfrimmer) lost its continuity in from eight to fourteen days. Hühne (1931) stressed the point that absorbability does not parallel holding strength. He placed great emphasis on the amount which catgut swells with moisture, stating that it tends to shorten when it swells. He regarded this as an important cause of its breaking. Accordingly, he recommended catgut sterilized with methyl violet and malachite green in oil, which swells much less than most varieties. After fourteen days the knot of such catgut is still intact, whereas he found the knot loose in the case of iodized gut and entirely gone in the case of plain catgut. He stated that fully iodized catgut requires from three to four weeks for organization and that the knots of the larger sizes may require from three to four months. The time required for organization differs widely with the vascularity of the part. This article contains some of the best photomicrographic reproductions of catgut in the process of absorption to be found in the literature.

In 1933 von Haefen made histologic studies on the absorption of iodized catgut in the muscles of the backs and in the subcutaneous tissues of kittens and came to the conclusion also that absorption was very slow. Still more recently Kraissl and Meleney (1934) proposed a method of testing the resistance of catgut to absorption in vitro. Under a strain produced by a 20 Gm. weight the ligature is incubated in 2 per cent solution of trypsin at p_H of 8, and the time required for it to break is measured. This is somewhat similar to the pepsin and hydrochloric acid digestion method used by Claudius in some of his experiments.

Nearly all the investigations of the absorbability of catgut have been either gross determinations of its presence or of its continuity in tissues or histologic studies of various phases of its persistence in tissues. Only Booth (1894), Phillips (1914), Howe (1928) and Kraissl and Meleny (1934) studied the absorption of catgut in terms of its tensile strength. None of these authors reported results with iodized catgut, though Phillips stated that his preliminary results with the catgut prepared by the Bartlett process were similar to those he reported with material prepared with cumene.

A number of authors, e. g., von Fillenbaum (1873), Callender (1874), Bruns (1875), Macewen (1881) and Borden (1897), studied the absorption of catgut in human tissues, but we have been unable to

find any studies on the effect of human tissue fluids on the tensile strength of the catgut.

Our interest in this subject has grown out of recent surveys of the incidence of rupture of the wound in the general surgical services at the Hospital of the University of Pennsylvania (Eliason and McLaughlin [1934] and Lewis [1934]). While the incidence was low, the mortality was considerable, and the complication was associated with eleven deaths in the periods covered by the surveys (about twelve years). Sokolov (1932) recently reviewed the literature on this subject. He estimated the incidence at from 2 to 3 per cent, which was somewhat higher than was found here.

The possible causes of this catastrophe are many, but perhaps the one most frequently imputed is premature weakening of catgut sutures. The relation of catgut to rupture of the wound has been suggested recently by Kennedy (1934), whose article would lead one to believe that rupture can be entirely avoided by using through and through nonabsorbable sutures, such as silkworm gut. It is also suggested by the occasional occurrence of two or three ruptures in close succession during the use of one lot of catgut and by the fact that in doing a secondary closure it is sometimes impossible to find any trace of the catgut originally used. The experience of investigators in retrieving sutures buried in the rectus muscles of dogs suggests another explanation of this sudden disappearance, namely, that the sutures become so surrounded with newly formed tissue that they escape observation. We have spent as long as ten minutes searching through a circumscribed area in a dog only to find a suture after shredding a considerable amount of tissue.

EXPERIMENTS

In order to see if there were any important differences in the rate at which the various kinds of catgut in use at the Hospital of the University of Pennsylvania lost their strength, a considerable number of samples have been tested after varying periods, during which they were implanted in animal tissues and thus subjected to the influence of the tissue fluids. In all, nearly a thousand tests of tensile strength have been made.

The most direct method of estimating the value of a given type of catgut for surgical use is to study it in the human patient and preferably in an abdominal wound. However, as the number of suitable patients available for this purpose is necessarily somewhat limited, preliminary experiments were done on dogs. Most of these were conducted by a technic that would be directly applicable to patients.

Before an attempt was made to compare the decline in tensile strength of different types of catgut, the variations between samples of unused catgut were investigated. All the determinations of the tensile strength were made with a modification of a Bureau of Standards thread-testing machine (fig. 1). By turning the crank at the lower left side, a strand of catgut held in the jaws of the machine is put under tension which is measured on the scale. The weight is moved along

the beam by the crank at the upper right side, which acts through a pair of gears at the fulcrum on a screw. The two cranks were manipulated so as to keep the beam freely suspended. When the tension is increased sufficiently, the sample breaks, allowing the beam to drop to rest. The scale reading is, strictly speaking, the yield strength, but for practical purposes it may be considered to be the tensile strength.

The samples were fastened at each end by steel clamps, which were tightened with screws. Considerable pressure was required to prevent slipping, and it was soon found that unless the steel jaws were covered with some softer material the catgut was pinched sufficiently to impair its strength seriously. Covering the jaws with cardboard increased the readings of the yield strength on the samples of a particular strand of no. 1 plain catgut from an average of 3.94 to 6.59 Kg. After trial of several substances, white rubber tubing, such as is often used to prevent stay sutures from cutting the skin, proved to be the most satisfactory

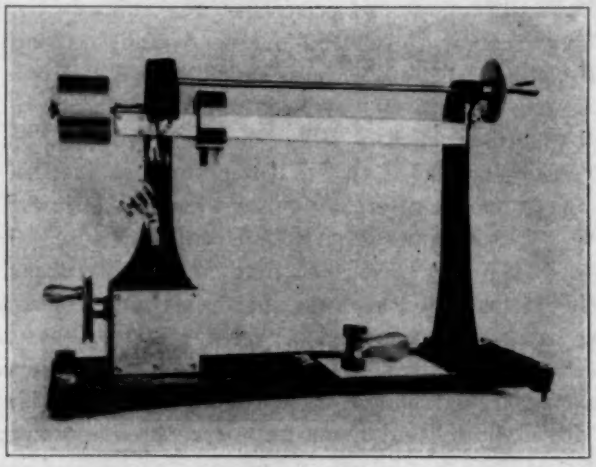

Fig. 1.—Apparatus for determining the tensile strength of catgut.

means of protecting the samples from the pinch of the clamps. A short section of the tubing was slipped over each end of the sample when it was clamped.

Commercial testing machines, such as are used for testing the strength of twine, etc., avoid inaccuracies due to the pinch of the clamps by taking a turn of the specimen about a 2 inch (5 cm.) cylinder before it is clamped. Special holders utilizing this principle were made for our apparatus. The cylinders were ½ inch (1.3 cm.) in diameter. Catgut which broke at an average of 5.93 Kg. when clamped with rubber tubing broke at an average of 5.69 Kg. when clamped with the special holders. These results are essentially the same in view of the wide variations that run through all catgut. As the special holders required inconveniently long specimens, the rubber tube method was used for all subsequent experiments.

The length of the specimens, which were tested without knots, was usually about from 3 to 4 cm. As tensile strength is affected to some extent by moisture, specimens removed from tissues were allowed to dry before being tested.

Variations between consecutive samples from a single strand of catgut were surprisingly large. While occasionally a strand of catgut

would be weaker throughout than others of the same size, type and brand, in general the variations between samples from different strands of the same kind of catgut were of the same order of magnitude as the variations between different samples of the same strand. The variations actually found in a few strands are shown in table 3. From four to thirteen samples from each strand were tested. The difference between the average strength of samples of corresponding products of the three manufacturers whose catgut was tested were in general less than that found between individual samples from any one strand. Considerable variation has been found before in tensile strength tests on catgut. This is evidenced by the fact that Minervini made six determinations and averaged the results to get each of his figures. Bullock, Lampitt and Bushill (1929) found it necessary to average twelve determinations for their work on physical and chemical factors

TABLE 3.—*Variability of the Strength of Catgut in a Given Strand (Manufacturer A)*

Kind of Catgut	Minimum Tensile Strength, Kg.	Maximum Tensile Strength, Kg.	Average Tensile Strength, Kg.
Plain no. 0	4.86	8.04	5.99
Plain no. 0	5.63	8.44	6.57
Plain no. 0	4.00	6.15	5.11
Chromic no. 0	3.37	5.12	4.16
Chromic no. 0	5.13	5.48	5.41
Iodized tanned no. 0	2.47	3.35	3.02
Iodized tanned no. 0	3.42	5.98	4.31

in the manufacture of catgut. The difference in strength between no. 0 and no. 1 catgut was about 23 per cent.

Significant differences in the initial strength were found between catgut of different types, that is, between plain, medium-hard chromic and tanned iodized catgut. The plain catgut was the strongest, and the tanned iodized catgut the weakest. The medium-hard chromic catgut of manufacturer A is advertised as ten to twenty day chromic catgut and that of the other two manufacturers, as twenty day chromic catgut. Tanned iodized catgut is iodized in addition to being chromicized.

The mean initial strengths of the varieties used are shown in table 4. Beside each figure are shown the number of samples tested and the number of tubes from which they came.

Experiments on Dogs.—In the work on dogs the wall of the abdomen was used as the site for implantation in all cases. In all the experiments on which the results are based the ends of the suture were left outside of the body so that the suture could be removed without incision. This method is applicable to patients,

and it permits different samples of the same piece of catgut to be withdrawn on successive days and tested. It is, however, open to the following criticisms:

1. As shown by Ilyin (1908) the skin affects catgut much more rapidly than muscle, fascia or the subcutaneous tissues.

2. As shown by Bruns (1875) and by others, the absorption of catgut is greatly accelerated by infection. There is a tendency for skin sutures to give rise to stitch abscesses, particularly when left for over a week.

3. The part played by subclinical infection, that is, by infection without suppuration, is not known. The deeper layers of the skin have been shown to harbor bacteria, even after careful disinfection of the surface. That such infection might accelerate absorption is conceivable. The hypothesis would furnish a facile explanation for Ilyin's observation. In experiments on patients absorption of catgut was more rapid in the wounds of inguinal herniorrhaphy, in which the roots of the pubic

TABLE 4.—*Mean Tensile Strength of Unused Catgut (Kilograms)*

Kind of Catgut	Manufacturer A	Manufacturer B	Manufacturer C
Plain no. 0	5.57 (24 samples, 10 tubes)	3.50 (9 samples, 9 tubes)	
Plain no. 1	6.83 (6 samples, 5 tubes)	5.22 (5 samples, 4 tubes)	
Chromic no. 0	4.66 (28 samples, 14 tubes)	4.88 (9 samples, 9 tubes)	5.50 (10 samples, 6 tubes)
Chromic no. 1	4.73 (8 samples,* 5 tubes)	5.84 (5 samples, 4 tubes)	
Tanned iodized no. 0	3.81 (20 samples, 8 tubes)	3.78 (1 sample, 1 tube)	5.16 (4 samples, 4 tubes)
Tanned iodized no. 1	4.97 (11 samples, 7 tubes)	4.57 (5 samples, 4 tubes)	

* One sample broke at 1.65 and was probably defective.

hair interfere somewhat with disinfection of the skin, than in other abdominal wounds.

The first criticism was met in our experiments by inserting a long enough section of the suture material into the deeper tissues, so that the portions in the skin could be avoided when the tensile strength was tested. The sutures were introduced on a long straight cutting edge needle, the point of which was forced through the skin and subcutaneous tissues and felt to pierce the fascia of the anterior rectus muscle before being brought out again. To prevent infection, careful asepsis was observed. The skin was prepared by shaving or close clipping and scrubbing with tincture of soft soap. It was then wiped off and painted with 7 per cent tincture of iodine and finally washed with 80 per cent alcohol.

The sutures were tied loosely so that they would not cut the skin, and an ample dressing was applied and protected with a strong binder.

Female dogs were selected whenever possible, and it was found essential to use animals with healthy coats.

When infections of the wound or stitch abscess occurred, the data were discarded. This invalidated several of the experiments on dogs but only a few of those on patients.

The influence of subclinical infection from the skin was tested to some extent by burying sutures completely and comparing their strength on removal with that of similar specimens inserted as skin sutures. The results were substantially the same. This, of course, does not exclude the possibility of such infection being present, but it does reduce the rôle it plays to the same rôle it might play in any wound which heals per primam intentionem. For this reason we feel that results by this method should have a more practical significance in relation to rupture of the wound than they would have had some more protected region of the body, such as one of the intraperitoneal organs, been used as the site for implantation.

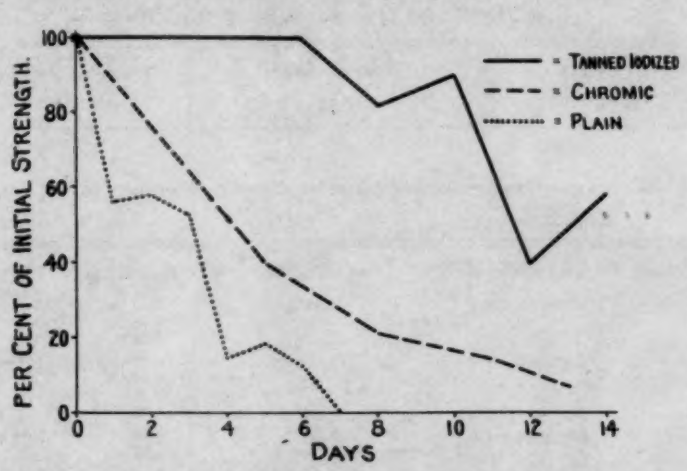

Fig. 2.—Graphs showing the strengths of samples of a single strand of catgut after the periods of implantation were increased in the same animal.

The results of the experiments on dogs have been expressed for the principal types of catgut tested in terms of the average daily decline in strength expressed as percentage of initial strength. This figure is computed as follows:

$$\frac{\text{(Initial Strength)} - \text{(Strength of the Last Specimen Tested)}}{\text{(Initial Strength)} \times \text{(Number of Days the Final Specimen Remained Implanted)}} \times 100$$

The results are shown in table 5.

Specimen graphs of individual experiments are shown in figure 2, each line representing the fate of one strand of catgut in a single dog.

Wide variations are again evident, but the data indicate a considerable difference between the three types of catgut. The chromic catgut retained its strength considerably longer than the plain catgut, as would be expected, but it was exceeded in durability still more by the tanned iodized variety. This was an unexpected finding.

Infection.—None of the experiments were directed toward studying the influence of infection, but in several of those instances in which

infection occurred, a rapid weakening of the suture material took place, as shown in table 6. This is in accord with many references in the literature to the fact that absorption of catgut is hastened by infection.

It was interesting to observe, however, that the effect was not pronounced with tanned iodized catgut.

While one does not anticipate infection in a clean abdominal wound, yet as infection does occur from time to time, this property of the tanned iodized suture may prove to be of tangible value.

TABLE 5.—*Average Daily Decline in Strength of Catgut of Manufacturers A and B in the Rectus Abdominis Muscles of Dogs*

Plain Catgut	Chromic Catgut	Tanned Iodized Catgut
14.1%	7.4%	2.8%

TABLE 6.—*Relation of Infection to Change in Tensile Strength After Contact with Body Fluids*

Manufacturer	Kind of Catgut	One Hour, Kg.	120 Hours, Kg.	Comment
A	Chromic no. 0	5.85	1.80 1.88 2.24	Not infected
A	Chromic no. 0	5.55	0.17 0.15 0.21 1.09	Infected
C	Chromic no. 0	5.54	2.34 1.95	Not infected
C	Chromic no. 0	5.07	1.35 0.24	Infected
A	Iodized tanned no. 1	4.04	3.37 3.69	Not infected
A	Iodized tanned no. 1	4.88	3.15	Infected
A	Iodized plain no. 1	6.51	3.26 2.97	Infected
B	Iodized tanned no. 0	3.78	2.00 2.34	Infected

Experiments on Patients.—The skin closure of a number of abdominal wounds was effected with catgut. The sutures were removed at various intervals of from one to twelve days and tested. All of the catgut used in this way was manufactured by Johnson and Johnson and was obtained from the regular stock of the general operating room. It was introduced as long vertical mattress sutures, so that about 3 cm. of catgut lay in the subcutaneous tissues. None of the wounds were drained except those in cases of operation on the gallbladder, and this was done as a safeguard against possible extravasation of bile or blood and not on account of infection. Mayer (1878) showed that human bile had little effect on catgut.

The data obtained are recorded in the graphs (figs. 3 to 8). When preliminary determinations of the initial strength were not made from a specimen of the catgut used, the average of all the other specimens of the same size and type of

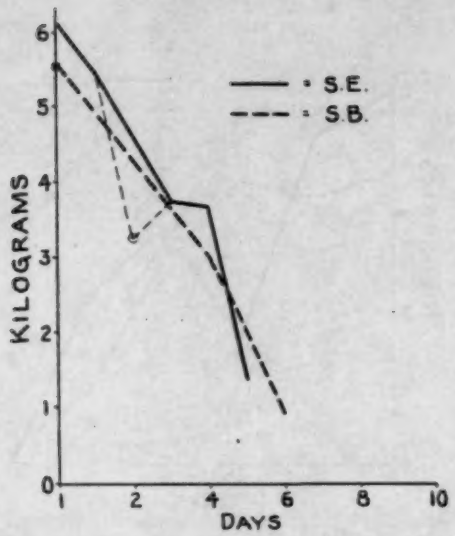

Fig. 3.—Graphs showing the decline in tensile strength of no. 0 plain catgut in patients S. E. and S. B.

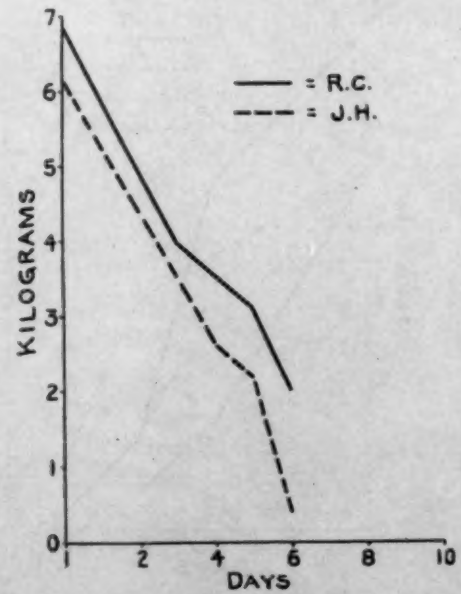

Fig. 4.—Graphs showing the decline in tensile strength of no. 1 plain catgut in patients R. C. and J. H. Infection of the wound developed in R. C. on the ninth postoperative day, and a small stitch abscess developed in J. H.

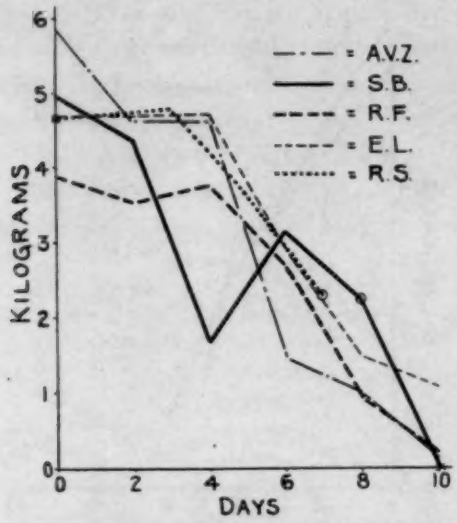

Fig. 5.—Graphs showing the decline in tensile strength of no. 0 chromic catgut (ten to twenty day) in patients A. V. Z., S. B., R. F., E. L. and R. S.

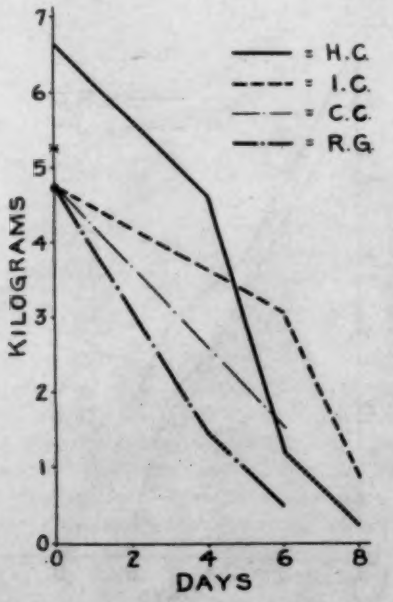

Fig. 6.—Graphs showing the decline in tensile strength of no. 1 chromic catgut (ten to twenty days) in patients H. C., I. C., C. C. and R. G.

catgut which were tested was used. Such averages are designated on the graphs by squares instead of dots. Points indicated by circles may be subject to some inaccuracy, as when specimens were too short to fit the testing apparatus readily.

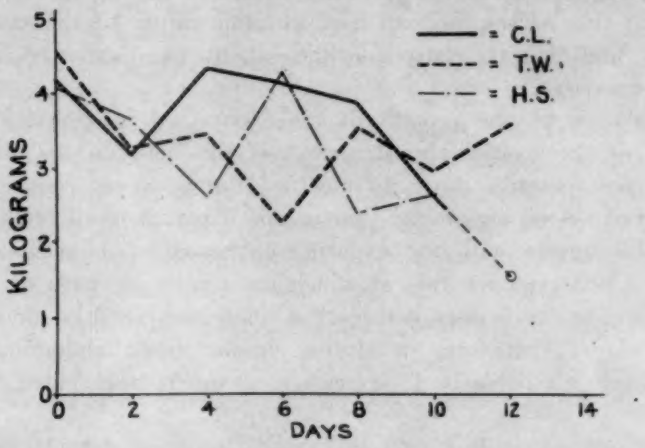

Fig. 7.—Graphs showing the decline in tensile strength of no. 0 tanned iodized catgut in patients C. L., T. W. and H. S.

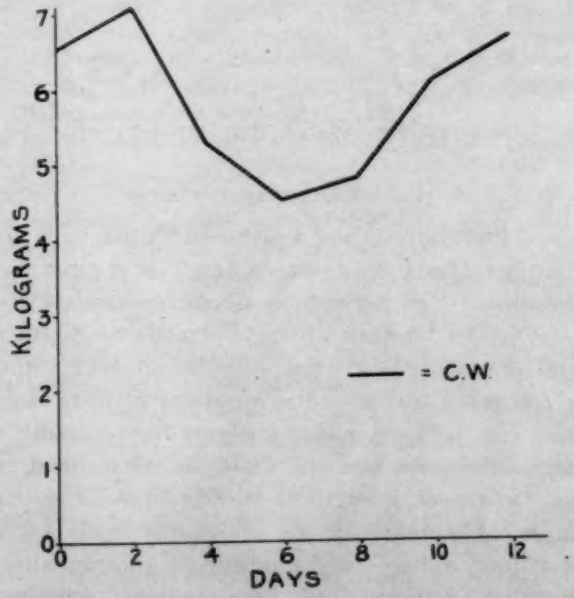

Fig. 8.—Graphs showing the decline in tensile strength of no. 1 tanned iodized catgut in patient C. W.

Infection occurred in two cases. In the first case a small purulent collection appeared a few days after all the specimens were removed, and in the second case a small bead of pus was present in the tract of one of the sutures. These two experiments were omitted from the averages shown in table 7.

From these data it appears that exposed to the subcutaneous tissues of man under actual operating conditions, Johnson and Johnson tanned iodized catgut has an average daily decline in tensile strength of less than half that of the medium hard chromic catgut of the same manufacturer and that the latter declines about two-thirds as rapidly as the plain variety.

As shown by the reports of cases collected by Sokolov (1931), rupture of the wound almost always occurs between the fourth and twelfth postoperative day. In most of the instances considered here it occurred by the eighth day, but in one it was delayed to the twelfth day. This agrees with the experimental work of Howes, Sooy and Harvey (1929) on the rate at which the tensile strength of a wound increases. Strength does not reach a maximum until on or about the twelfth day. Therefore, in closing fascia in an abdominal wound with catgut, particularly if excessive strain is anticipated, as from

TABLE 7.—*Average Daily Decline in Tensile Strength of Johnson and Johnson Catgut in the Subcutaneous Tissues of Patients*

Kind of Catgut	Percentage
Plain	14.8
Chromic	10.9
Tanned iodized	3.5

coughing or distention, we believe that tanned iodized catgut is the safest variety to use.

SUMMARY

The medical literature on the absorption of catgut is reviewed.

Tensile strength tests on fourteen kinds of catgut were made to show the variations: (*a*) between consecutive samples from the same strand of catgut; (*b*) between different strands of catgut of the same size, type and brand; (*c*) between sizes 0 and 1 of catgut otherwise identical; (*d*) between corresponding products of three different manufacturers, and (*e*) between plain, medium hard chromic and tanned iodized catgut of the same size and from the same manufacturer.

The decline in tensile strength of several kinds of catgut was tested by implantation of samples in the abdominal walls of dogs. This showed that tanned iodized catgut possessed substantially more resistance to the action of tissue fluids than medium hard chromic catgut.

Evidence was obtained which showed that tanned iodized catgut was much less affected by infection than medium-hard chromic or plain catgut.

About one hundred specimens of Johnson and Johnson catgut were implanted as skin sutures in abdominal wounds of patients. These

were withdrawn at intervals of from one to twelve days, and graphs were made of the results. The data showed also that tanned iodized catgut loses its strength much more slowly than medium-hard chromic catgut.

The decline in strength of catgut in man is approximately the same as in the dog.

As the methods of manufacturers of catgut are little publicized and of course subject to change without notice, the investigation of any particular brand of catgut may be of rather temporary significance. It is, however, a fairly simple matter to test catgut for its lasting power either at regular intervals or whenever suspicion of change arises. We are convinced that man is the most suitable subject for these experiments as well as being the most easily available to the practicing surgeon.

Dr. I. S. Ravdin gave suggestions and criticisms in connection with this work.

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INFLUENZAL MENINGITIS

REPORT OF A CASE WITH RECOVERY

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NEW ORLEANS

Individual case reports should be made if there are sufficient grounds for believing that something unusual is to be presented. In the instance under consideration there are many instructive, puzzling and gratifying experiences which form the basis for inquiry and for a statement of the record.

Deductions of dogmatic character cannot be drawn, but it is safe to add these experiences to those already accumulated, and from the whole some inference may be justifiable.

In order to bring the problem at once before the reader, a summary of the salient facts will be given here and elaborated on later in the paper.

REPORT OF CASE

S. S., a child aged 11 years, was injured in an automoble accident on March 23, 1935. He was picked up by a passing motorist and taken to an institution, where roentgenograms of the skull and one of the clavicle were taken. The original pictures were interpreted as "negative for bone injury." After receiving this report I had the child immediately transferred to the Touro Infirmary, where roentgenograms were again taken of the clavicle and the skull.

From the roentgenologic department the child was taken to the operating room. He was alert and excitedly conscious. The skin was extremely pale, cold and clammy. The pupils were equal and reacted to light and in accommodation. The only evident deformity was that of the left clavicle, which showed a definite angulation and a fulness in the left supraclavicular region; the shoulder on that side was on a lower level than that on the right. A bleeding wound behind the left ear was noted. In order to determine the nature of this wound ethylene was administered. When the flap of skin behind the ear was elevated, a tongue of lacerated brain tissue was seen protruding through an opening in the skull, which could easily have admitted the tip of the little finger. There was a free discharge of cerebrospinal fluid. Above the ear there was a definite depression. A prophylactic dose of mixed gas gangrene and tetanus serum was given.

He was returned to the room; an infusion of a 5 per cent solution of dextrose was given, and 3 ounces (88.7 cc.) of magnesium sulfate was ordered given by rectum every eight hours. Heat was applied to the extremities and an ice bag to the skull.

An oculist, Dr. Hardin, examined the eyegrounds immediately and at frequent intervals during the patient's stay in the hospital. At no time did he find evidence suggestive of increase of intracranial tension.

From the Department of Surgery, Graduate School of Medicine, Tulane University, and Touro Infirmary.

After receiving 500 cc. of the dextrose infusion the patient had a severe chill and became irrational and extremely restless. The restlessness persisted for hours, as did the incoherent talking. Vomiting, which began two hours after admission, persisted.

Readings of blood pressure were made at frequent intervals. The variations were slight, the pressure remaining between 115 systolic and 75 diastolic and 108 systolic and 70 diastolic.

The patient's color remained good; the volume of pulse was good, the rate was 90 and the rhythm was regular.

On March 28, five days after the accident, the child had a chill and a rise of temperature to 102.4 F. The wound was inspected and found to be granulating. There was no evidence of local infection, and the regional lymph nodes were not enlarged. There was a marked rise in the pulse rate.

Two conditions were thought of, one the possibility of an infection of the upper respiratory tract and the other a delayed serum reaction. The blood count at that time showed a white cell count of 5,650, with 8 per cent eosinophils. Because of the leukopenia, the general condition of the wound, the absence of swelling in the left side of the neck in the region of the jugular vein and the absence of regional glandular enlargement, I did not feel that the fever was due to an intracerebral condition or thrombosis of the lateral sinus. He complained of a general itching of the body, and this, coupled with the fever, suggested a delayed serum reaction.

The following day edema of the face, generalized urticaria, itching and vomiting, with persistence of fever, left no doubt that I was dealing with a serum reaction. The febrile reaction persisted for two days, after which the convalescence was so uneventful that it was hard to believe that a patient who had been so seriously injured was improving so consistently.

The child was kept in the hospital until April 13, when he was allowed to go home in the ambulance; there he was kept quiet and under a strict regimen to avoid anything which might give rise either to an infection or to an increase in the intracranial tension, the possibility of abscess of the brain or meningitis as sequelae being kept in mind.

All went well at home until April 24, when the child complained of a headache and a sore throat. Dr. Taquino, an otolaryngologist, noted a redness of the throat, which he thought might possibly account for the fever.

The following morning a blood count was made by Dr. Foster Johns. The leukocyte count was 23,500, with 95 per cent neutrophils. Examination of the urine showed a trace of albumin, sugar and numerous hyaline casts.

The child was immediately taken to the Touro Infirmary. On examination it was noted that the pupils were equal, reacted to light and in accommodation and revealed no evidence of an oculomotor disturbance. The eyegrounds were normal. Dr. Taquino reported that the ear drum was red, but it did not bulge. The eyes were examined, and no evidence of pressure was noted.

A roentgenogram of the skull was taken, and this showed cloudiness in the region of the left mastoid and the old depressed fracture.

Because of the headache, vomiting and febrile reaction, the presence of sugar in the urine and the marked leukocytosis, it was decided to do a spinal tap to determine the presence of meningitis.

Ethylene anesthesia was used. The spinal fluid obtained was cloudy. A mercury manometer registered a pressure of 40 mm. The pressure was reduced to less than 12 mm. by drainage. While the child was under the influence of the anesthetic, paracentesis of the left ear was done and thick pus was evacuated.

TABLE 1.—*Résumé of Findings on Spinal Punctures*

Date	Pressure Before Tap, Mm. of Hg	Pressure Reduced to Mm. of Hg	Quantity of Fluids Removed, Cc.	Color of Fluid	Cell Count	Globulin	Differential Cell Count	Culture
4/25/35	40	12	..	Cloudy	10,800	4 plus	78 per cent neutrophils; 22 per cent lymphocytes	Gram-negative bacilli, morphologically B. influenzae
4/26/35	26	10	..	Less cloudy	11,400	3 plus	Few lymphocytes; many pus cells	Gram-negative bacilli, morphologically and culturally B. influenzae
4/27/35	50	..	90	Cloudy	6,400	2 plus	.....	Gram-negative bacilli, morphologically and culturally B. influenzae
4/28/35	20	12	45	Cloudy	1,150	1 plus	.....	Gram-negative bacilli, morphologically and culturally B. influenzae
4/29/35	50	12	..	Flakes	320	1 plus	.....	Morphologically and culturally B. influenzae
4/30/35	22	10	45	Clear	325	1 plus	.....	.....
5/ 1/35	60	12	60	Cloudy	600	1 plus	.....	.....
5/ 2/35	90	8	60	Cloudy	1,075	1 plus	.....	.....
5/ 3/35	80	10	45	Not so cloudy	1,110	1 plus	.....	Pellicle formation; smear contained all polymorphonuclear cells; no organisms
5/ 4/35	62	4	45	Much clearer	625	1 plus	.....	.....
5/ 5/35	56	4	..	Much clearer	825	1 plus	.....	.....
5/ 6/35	66	6	50	Flakes	1,170	Negative	100 per cent polymorphonuclears; no organisms	B. influenzae
5/ 7/35	60	10	..	.....	2,550	2 plus	.....	B. influenzae
5/ 8/35	66	8	50	.....	1,460	1 plus	80 per cent neutrophils	B. influenzae
5/ 9/35	66	8	98	Much clearer	725	1 plus	.....	B. influenzae
5/10/35	66	6	..	Clear	850	1 plus	.....	No growth
5/11/35	44	8	30	Clear, few flakes	375	1 plus	.....	No growth
5/12/35	44	8	15	Clear	505	Negative	.....	No growth
5/13/35	42	8	30	Yellowish tinge	325 (polymorphonuclears in red blood cells)	1 plus	.....	No growth
5/14/35	42	8	20	Xanthochromia	78 (polymorphonuclears)	1 plus	.....	No growth
5/15/35	34	8	50	Clear	85 (polymorphonuclears)	1 plus	.....	No growth
5/17/35	40	8	40	Clear	162	.....	60 per cent lymphocytes, 40 per cent polymorphonuclears	No growth

TABLE 1.—*Résumé of Findings on Spinal Punctures—Continued*

Date	Pressure Before Tap, Mm. of Hg	Pressure Reduced to Mm. of Hg	Quantity of Fluids Removed, Cc.	Color of Fluid	Cell Count	Globulin	Differential Cell Count	Culture
5/19/35	38	10	40	Clear	105 (few polymorphonuclears)	Slight trace	.....	No growth
5/20/35	40	8	50	Clear, flakeless	...	Negative	35 per cent lymphocytes	.....
5/23/35	28	10	25	Clear, few flakes	...	Slight trace	70 lymphocytes; 5 per cent polymorphonuclears	Gram-positive cocci, Staphylococcus aureus
5/26/35	26	8	20	Clear	52	Slight trace	.....	Negative
5/31/35	12	..	1	Clear, no flakes	...	.....	26 lymphocytes	No growth

When the child awakened, he was mentally clear and there was less headache. An organism morphologically and culturally Bacillus influenzae was noted in the spinal fluid. The white cell count was 10,800.

The following morning, April 26, the child complained of a headache and of pain and stiffness of his neck. The reflexes in the extremities were not exaggerated. The temperature rose to 104 F. The pulse rate ranged between 120 and 140. The pupils remained equal.

A second spinal tap was done at 1 p. m. The pressure was found to be 26 mm. The fluid was cloudy but less so than the day before.

On April 27 the temperature reached a maximum of 104.6 F. Neither vomiting nor drowsiness was noted.

The daily spinal tap revealed a pressure of 50 mm., but the fluid seemed less cloudy. About 90 cc. of spinal fluid was withdrawn before the pressure was reduced to 12 mm.

After the tap the patient ate well. He complained of headache only during the afternoon. He slept the greater part of the night quietly and without drugs.

On April 28 the child seemed alert, felt well, with no headache, nausea or vomiting and was interested. Spinal tap was performed; the maximum pressure was 20 mm. The fluid was distinctly less cloudy than on previous occasions; the pressure was reduced to 12 mm. by the removal of 45 cc. The blood pressure was 128 systolic and 85 diastolic.

On April 29 spinal tap was performed; the pressure was from 46 to 50 mm. and was reduced to 12 mm. The blood pressure was 118 systolic and 85 diastolic.

On April 30 spinal tap was performed; the pressure was 22 mm. It was reduced to 11 mm. when 45 cc. of fluid was drained.

On May 1 spinal tap was performed; the pressure was 60 mm. and was reduced to 12 mm. The fluid was slightly cloudy. A transfusion of 200 cc. of whole blood was made.

On May 2 headache was complained of. The pressure of the spinal fluid was found to be 90 mm. It was reduced to 10 mm. when 60 cc. of fluid was withdrawn.

On May 3 spinal tap was performed with the patient under general anesthesia. The pressure was 80 mm.; 45 cc. of fluid was removed, and the pressure was reduced to 10 mm. The fluid was much clearer.

On May 4 spinal tap was performed. The pressure was 62 mm. About 50 cc. of fluid was withdrawn, and the pressure was reduced to 4 mm. The fluid was clear.

On May 5 spinal tap was performed; the pressure was 56 mm. The fluid seemed clearer than on May 4. Blood was taken for a count.

After puncture the patient rested well, not complaining of headache, and was mentally more alert. The pulse was of good volume; the rate was 100. He took nourishment freely. The temperature was 102.2 F.

On May 6 spinal tap was performed at 8:15 a. m. The pressure was 66 mm. Flakes were present. About 50 cc. of fluid was withdrawn and the pressure was reduced to 6 mm.

Eight hours after the tap the patient complained of pain in the back of the head. The pain did not seem to be more severe than that felt at the same time on May 6. The blood pressure was 102 systolic and 72 diastolic. No change was noticeable in the volume of the pulse. The patient was mentally clear.

TABLE 2.—*Results of Examination of Blood*

				Smear						
Date	Red Cells	White Cells	Hemoglobin Content, %	Segmented Cells, %	Staff Cells, %	Young Forms, %	Polymorphonuclears, %	Lymphocytes, %	Monocytes, %	Eosinophils, %
3/24/35	4,070,000	11,450	..	74	7	0	..	16	2	1
3/28/35	5,200,000	5,650	..	..	..	..	72	19	1	8
3/30/35	.....	7,850	..	..	..	..	37	58	1	4
4/26/35*	4,570,000	18,500	78	52	42	3	..	6	..	..
4/28/35	4,320,000	10,750	75	40	25	5	..	28	2	..
5/ 1/35	4,575,000	27,750	75	..	..	..	85	14	1	..
5/ 5/35	4,715,000	22,500	75 to 80	..	..	..	78	19	3	..
5/ 9/35	4,625,000	14,500	75	..	..	..	84	40	3	..
5/19/35	4,710,000	9,500	80	..	..	..	57	40	3	..

* On April 26 the sugar content of the blood was found to be 100 mg. per hundred cubic centimeters.

On May 8 spinal tap was performed; the pressure was 66 mm. About 56 cc. of fluid was withdrawn, and the pressure was lowered to 8 mm. A transfusion of 250 cc. of whole blood was given.

On May 9 spinal tap was performed in the morning; the pressure was 66 mm. About 98 cc. of fluid was withdrawn, and the pressure was reduced to 8 mm. The fluid seemed to be much clearer than it was on May 8. At 10:30 a. m. the patient was awake and ate breakfast. He said that the headache was better. He was mentally very clear and observant. The pulse showed good volume.

On May 10 spinal tap was performed; the pressure was 66 mm. and was reduced to 6 mm. The fluid was clear. Two hours later he was awake and not complaining of headache.

On May 11 spinal tap was performed; the pressure was 44 mm. The fluid was clear, with few flakes. About 30 cc. was withdrawn, and the pressure was reduced to 8 mm.

On May 12 spinal tap was performed; the pressure was 44 mm. and was reduced to 8 mm. About 15 cc. of fluid was removed. The fluid was much clearer than it had been at any time; few flakes were present.

On May 13 spinal tap was performed; the pressure was 42 mm. and was reduced to 8 mm. The fluid had a yellowish tinge. Although the pressure was

less than it had been on May 12, the total amount of fluid withdrawn was greater—about 30 cc. Five hours later the patient was talking, very responsive and not complaining of headache.

On May 14 spinal tap was performed; the pressure was 42 mm. About 20 cc. of fluid was removed. The yellow tinge was still present. The patient was sleeping. Examination of the eyes showed no abnormality.

On May 15 spinal tap was performed; the pressure was 34 mm. and was reduced to 8 mm. by removal of about 50 cc. of fluid. The fluid was clear, showing only a slight trace of xanthochromia, if any.

On May 16 the patient appeared alert and did not complain of any pain.

On May 17 spinal tap was performed for the first time since May 15. For several hours the child had no headache. The spinal fluid pressure was 40 mm. and was reduced to 8 mm., about 40 cc. of fluid being withdrawn. The fluid was clear, with few flakes.

On May 19 spinal tap was performed; the pressure was 38 mm. and was reduced to 10 mm. About 40 cc. of fluid was removed. It was clear, with few flakes. Notes made that evening reported that the patient was alert and very talkative, making no complaint of pain. The blood pressure was 112 systolic and 88 diastolic.

On May 20 spinal tap was performed; the pressure was 40 mm. and was reduced to 8 mm., about 50 cc. of clear, almost flakeless fluid being withdrawn.

On May 21 the patient did not complain of any discomfort and was alert and responsive to all questions.

On May 22 the patient had a comfortable day. He did not complain of headache. He was very alert and did not want another spinal puncture done.

On May 23 spinal tap was performed at 8:30 a. m.; the pressure was 28 mm. and was reduced to 10 mm., about 25 cc. of fluid being withdrawn. The fluid was clear, with very few flakes. Eight hours after the spinal tap the child was talkative, alert and much interested.

On May 25 the patient was talkative and alert and had no headache.

On May 26 spinal tap was performed; the pressure was 26 mm. and was reduced to 8 mm., about 20 cc. of clear fluid being removed.

On May 27 the patient was talkative and had had no headache for over a week.

The last spinal tap was performed on June 2, the pressure being 12 mm. The fluid was clear, with no flakes. One cubic centimeter was removed for a cell count.

On June 4 the report showed that the patient had been alert and uncomplaining so far as headache was concerned. The bowels had acted freely. The urine was free from reducing action. No disturbance of vision was apparent. The general appearance was excellent. He had been in the courtyard for the past several days.

On June 11 examination of the eyes showed no abnormality. The eyegrounds were normal. Daily examinations were made by the oculist, and at no time did he observe changes of the retina.

COMMENT

Looking back over this case, I find that the interpretation of the original roentgen plates failed to give the information that the depressed fracture of the skull existed. Even a repetition of the roentgen examination after the clinical examination had definitely shown the existence of the compound fracture with laceration of the brain failed to demon-

strate satisfactorily the abnormal opening in the skull. This may be accounted for by the fact that a Bucky diaphragm was not used. Whatever the reason, this is evidence that the laboratory diagnosis should not be used to the exclusion of a clinical examination. This is an additional proof of the necessity for making a careful examination in order that one may not be misled by diagnostic aids. The day of the clinician is not over. Careful examination, the utilization of all clinical data and the exercise of judgment acquired by years of experience are not to be replaced by the exclusive reliance on laboratory data.

The mortality from head injuries has been materially diminished, as statistics show, by the use of conservative, nonoperative measures. The treatment instituted in this case consisted of dehydration and limited intake of fluid. Magnesium sulfate was given by rectum instead of by the oral route, because it is desirable to avoid anything which will even temporarily raise the intracranial pressure. Vomiting raises the intracranial pressure. Magnesium sulfate administered by mouth at times produces this unwanted symptom.

At the time of the accident there was no indication for spinal drainage, as there was a persistent cerebrospinal decompression through the dural wound. Fortunately there did not develop an infection at the site of the wound; in fact, the wound granulated rapidly and healed like a wound of the mastoid.

At no time did the eyegrounds show any abnormal changes. This I took to be a good sign, indicative that the intracranial pressure was not increased. That this was not a justifiable conclusion the subsequent course proved.

With the sole exception of the serum reaction, the convalescence of the patient from the fracture and laceration of the brain was uneventful; his wound granulated well, and no manifestations of intracranial pressure developed.

When the prospects seemed to be better, the family were anxious for a favorable prognosis. Late manifestations of abscess of the brain or meningitis were kept in mind, and a guarded prognosis was given. Continually the attitude was assumed that each day represented so much gained.

As stated before, on April 13, twenty-one days after the accident, the patient was taken home. Still the caution was observed of keeping him quiet, undisturbed by company.

All went well for two weeks, when the child complained of headache, and the nurse noted a temperature of 101 F. As noted in the record, he was examined by Dr. Taquino, who found evidence of a red throat, which suggested that the fever might be due to an intercurrent infection of the respiratory tract. However, evidence of marked leuko-

cytosis, there being 23,500 white blood cells, with 90 per cent neutrophils, an increased pulse rate and urinary findings of sugar, albumin and casts, added to the symptoms of headache, nausea and vomiting, pointed to the need for immediate spinal puncture.

On his return to the hospital this was done, and the spinal fluid, which was under pressure of 40 mm. of mercury, was observed to be cloudy. After the spinal tap the middle ear was drained of thick purulent material by Dr. Taquino, the otolaryngologist.

It should be observed at this point that the diagnosis of meningitis might have been delayed if the ear had been punctured before the tap, because finding pus in the middle ear might have made one hesitant to do a spinal puncture. It might have been argued that the infection of the ear accounted for all the symptoms.

The report from the laboratory on the spinal fluid was anxiously awaited. The cell count was 10,800 and the reaction for globulin three plus, and a gram-negative bacillus, morphologically B. influenzae, was recovered from the culture.

Here, then, I was confronted by influenzal meningitis. What could be done and what was the prognosis? Little comfort could be obtained by reference to the literature and less from my colleagues.

A definite policy was adopted at once. It was decided to do daily spinal taps and repeated transfusions. In all, twenty-nine taps were done. The manometric readings during the first two weeks varied between 40 and 60 mm.; during the third, fourth and fifth weeks the pressure varied between 90 and 60 mm. Globulin, varying in quantity, was always present. The cell count varied between 11,400 and 52 during the convalescence. At one time the cells were all polymorphonuclear, and culturally an organism morphologically B. influenzae was observed during the first four weeks. The fluid varied from very cloudy to cloudy with flakes, and during the fifth week a definite xanthochromia developed. This persisted for a few days. The temperature ranged from 104.6 F. to 100 F. for four weeks; then the maximum temperature gradually declined to 100 F. and remained at that level with fluctuations down to 99 F. for another four weeks.

At no time during the illness was the child irrational; on the contrary, he was alert. When the pressure was high during the morning before the tap, he complained of a violent headache. Nausea and vomiting were not prominent manifestations.

A remarkable aspect of the case was the absence of disturbances of the eyegrounds; there was never any evidence of papilledema or retinal hemorrhage in spite of an intracranial pressure which reached a level of 90 mm. at one time. Neither did diplopia or other pressure phenomena develop.

It is hard to believe that an intracranial pressure of 90 mm. of mercury can exist without producing some signs in the eyes. It is the unusual, unexplainable manifestation which divests dogmatism of authority.

These facts demonstrate that evidence of increased intracranial pressure is not always obtainable by the expected changes in the eyegrounds. Dr. Hardin has informed me that in many cases of increased intracranial tension similar negative findings have been reported.

The policy of treatment consisted, in addition to the daily spinal taps, of repeated transfusions of whole blood, administration of magnesium sulfate by rectum for dehydration, a dry diet and the use of hypnotic drugs to overcome restlessness.

One may well imagine that the finding of meningitis culturally due to the influenza bacillus caused great concern. Turning to the literature, one finds many interesting clinical reports, compilations, experimental observations and deductions. In 1931 Bloom,[1] of New Orleans, reported a recovery after treatment by repeated spinal taps and replacement by convalescent serum. It is interesting to note that after twelve days of punctures and replacement with serum the culture was positive for four consecutive days in his case. Bloom reviewed the literature up to that time. He noted that the mortality was 92.5 per cent. In all the literature he was able to find reports of only twenty-four cases in which the patient had recovered.

In 1931 Jenks and Radbill [2] reported the cases of ten patients treated with influenza serum without a recovery.

In 1933 Wilkins [3] reviewed the literature. The following is quoted from his article:

> There are reports of only eight cases treated by serum—complement mixtures. In these cases the dose was 6-8 cc. of fresh human serum plus 15 cc. of influenzal antiserum. Treatment was given twice a day, alternating ventricular and lumbar injections with occasional cisternal injections. Ward states, "In the first five cases some improvement took place temporarily, although all of the five patients died eventually. In the next two cases, the disease was very far advanced on admission to the hospital, and not even temporary improvement was noted. . . ."
>
> Since recoveries do occur spontaneously and have been reported in cases treated by lumbar puncture alone, by antimeningococcus serum, by influenzal vaccine, and by convalescent serum, great caution must be used in attributing any recovery to the therapeutic agent employed.

In 1934 Neal, Jackson and Appelbaum [4] reviewed their own experiences in the treatment of one hundred and eleven patients, with four

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1. Bloom, C. J.: New Orleans M. & S. J. **83**:455, 1931.
2. Jenks, H. H., and Radbill, S. X.: Arch. Pediat. **48**:1, 1931.
3. Wilkins, Lawson: Internat. Clin. **2**:300, 1933.
4. Neal, Josephine B.; Jackson, H. W., and Appelbaum, Emanuel: Meningitis Due to the Influenza Bacillus of Pfeiffer (Hemophilus Influenzae), J. A. M. A. **102**:513 (Feb. 17) 1934.

recoveries. Their four instances of recovery brought the number up to thirty-five. The mortality, as cited by them, is 96.4 per cent.

They stated:

> A study of the treatment of these thirty-five patients who recovered shows that twenty-six had lumbar punctures only or lumbar punctures supplemented by nonspecific therapeutic measures. The use of "convalescent serum" is mentioned in three instances. This, however, cannot be regarded as specific therapy, since the serum was obtained from individuals who had recovered from clinical influenza, which is not now considered to be caused by influenza bacilli. It seems obvious, therefore, that lumbar puncture is an important therapeutic measure. . . . Only eight patients received antiinfluenza serum. Of these, four patients were in our own group, and . . . in none of them could the use of the specific treatment be regarded as a determining factor in recovery.
>
> Further research should be done toward the development of a more potent serum with high antitoxic as well as antibacterial properties.

One of the most important contributions to the subject was the work of Margaret Pittman,[5] published in 1933. She stated that the organisms present in influenzal meningitis are "type specific" and "immunologically identical." This fact suggested to her as it did to other observers that a highly immune serum might have a specific therapeutic value.

Martha Wollstein, according to Neal, gave "the first real impetus to the study of influenza bacillus meningitis" (1911).

Wollstein did not find Haemophilus influenzae antiserum effective in treating children, although she found it effective in treating monkeys suffering from meningitis experimentally produced.

Pittman reported that eighteen patients have been treated by means of intrathecal injections of immune horse serum. She stated: "The results do not indicate that this form of specific therapy carried out under given directions was of great practical value."

It is at the present time accepted generally that influenzal meningitis is a primary disease. A great many of the observers have shown that an infection of the respiratory tract did not precede the onset of influenzal meningitis. Since there is not sufficient evidence to support the idea that such infection is a precursor of influenzal meningitis and since immunity from infection with influenza or grip is transient, the suggestion of using human serum from a patient who had influenza was not accepted in my case. Had I used it and had the patient recovered, I should have been inclined to attribute the happy result to the serum.

The results thus far obtained from influenza antiserum, or horse serum, given intraspinally are, to say the least, not impressive. When so large an area as the cerebrospinal system is involved, any agent to be effective must bathe the entire area in sufficient concentration to be able

5. Pittman, Margaret: J. Exper. Med. **58**:683, 1933.

to combat effectively the living colonies present. It seems more logical at present to depend on drainage. Drainage favors natural irrigation. As long as the infection is present, the sources of serous fluids are stimulated to increased output. This has been demonstrated beautifully in the epoch-making work of Willems on joints.

The hyperactivity of the choroid plexus in the presence of infection is great. Free drainage is a surgical principle. All who have reported on the treatment of meningitis of influenzal character have advocated repeated spinal taps.

Repeated spinal taps were performed daily in this case, fluid being removed in variable quantities, and each time the tap was done an effort was made to reduce the pressure to slightly above the normal.

Several things were particularly noticeable about the results of the spinal drainage: 1. The quantity of fluid removed to reduce the pressure to a certain level was not constant. 2. The presence of flakes increased in proportion to the diminution of the cloudiness in the fluid. 3. As the cloudiness and the number of flakes diminished, the pressure became notably lower. 4. At one time the spinal fluid showed a definite xanthochromia. 5. The spinal fluid remained culturally positive for four weeks. 6. When the culture became negative, the temperature curve began to decline. These observations, with accumulated evidence from other cases, may prove to be of value.

Believing that the logical method of handling a patient with such a condition consisted of repeated taps and transfusions, I used these procedures as sheet anchors, and all other methods were avoided. No other procedures have been so consistently utilized in the reported cases in which the patient recovered. So far it seems that other procedures have been incidental to the individual patient's recovery.

SUMMARY

This case has been reported in detail for the following reasons:

1. A child who had a compound depressed fracture of the skull with brain laceration and a fracture of the clavicle recovered.

2. This patient five weeks after the accident acquired acute influenzal meningitis.

3. A persistent increased intracranial pressure, varying from 90 to 40 mm., was never associated with changes of the eyegrounds.

4. After 29 spinal taps and three transfusions I was fortunate enough to be able to report a complete recovery without evidence of any residual manifestations.

5. Up to the time of writing the efforts to prove the efficacy of so-called immune human serum have not been satisfactory.

6. It seems generally accepted that influenzal meningitis is a primary disease not associated with a previous infection of the respiratory tract in the majority of instances.

7. The organism causing influenzal meningitis is immunologically type specific.

8. The efforts thus far to effect cures with immune horse antiserum have failed in the human patients, although it has been effective in monkeys experimentally infected.

9. Until an effective antiserum is available, repeated spinal taps, transfusions, dehydration and sedatives remain the most valuable methods of attempting to aid influenzal meningitis.

10. The mortality remains about 96 per cent.

11. There is much work to be done before this dreaded disease is taken out of the column of almost certainly fatal diseases.

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INTRAMURAL FORMATION OF GALLSTONES

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Very little appears in the English medical literature concerning the formation of gallstones in the wall of the gallbladder. In fact, it has been impossible to find a single article which describes this condition fully.

Rolleston and McNee [1] briefly stated that intramural gallstones may occur, and in Sieveking's English translation of Rokitansky's "Manual of Pathological Anatomy," published in 1855,[2] a note is found regarding the occurrence of such stones.

Stones within the wall of the gallbladder were first described by Morgagni [3] in 1761 in his famous "De sedibus et causis morborum." He thought that the stones originated in small glands. Outpouchings of the mucosa of the gallbladder into the external layers of its wall were first noted by Rokitansky in 1842,[4] and in the English edition of the previously mentioned manual there occurs this sentence: "Small calculi are also occasionally formed within small saccular dilatations of the biliary mucous membranes and may appear to lie external to the cavity of the gallbladder." In the German edition of the same book, published in 1861,[5] Rokitansky again stated that hernia-like diverticula of the mucous membranes are present in the gallbladder sometimes in great numbers, but that they are usually insignificant, with very small openings into the lumen, which explains why the dark-colored concretions often found in them appear to be placed between the layers of the wall of the gallbladder.

In 1858 Luschka [6] published his first study on the glands of the human gallbladder. He may well have observed what will later be

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1. Rolleston, H., and McNee, J. W.: Diseases of the Liver, Gall-Bladder and Bile-Ducts, London, The Macmillan Company, 1929, p. 780.

2. Rokitansky, C.: A Manual of Pathological Anatomy, translated by E. Sieveking, Philadelphia, Blanchard & Lea, 1855, vol. 2, p. 130.

3. Morgagni, J. B.: De sedibus et causis morborum, translated by B. Alexander, London, Millar & Cadell, 1769, book 3, vol. 2, letter 37, article 21, p. 235.

4. Rokitansky, C.: Handbuch der speziellen pathologischen Anatomie, Wien, Braumüller and Seidel, 1842, vol. 2, p. 374.

5. Rokitansky, C.: Lehrbuch der pathologischen Anatomie, Wien, W. Braumüller, 1861, vol. 3, p. 282.

6. Luschka, H.: Die Drüsen der Gallenblase des Menschen, Ztschr. f. rat. Med. **4**:189-192, 1858.

termed "Rokitansky-Aschoff sinuses," but he is given credit only for describing the so-called "true Luschka ducts." He studied gallbladders by rendering their mucous membrane transparent with acetic acid and then placing them on a glass slide in front of a bright light. By this means he found glands in the submucosa to be more numerous in the lower segment of the gallbladder. In some glands he found granular detritus and in others "bile-pigmented molecules." Cysts were also found in the submucosa, which he thought to be cystic degeneration

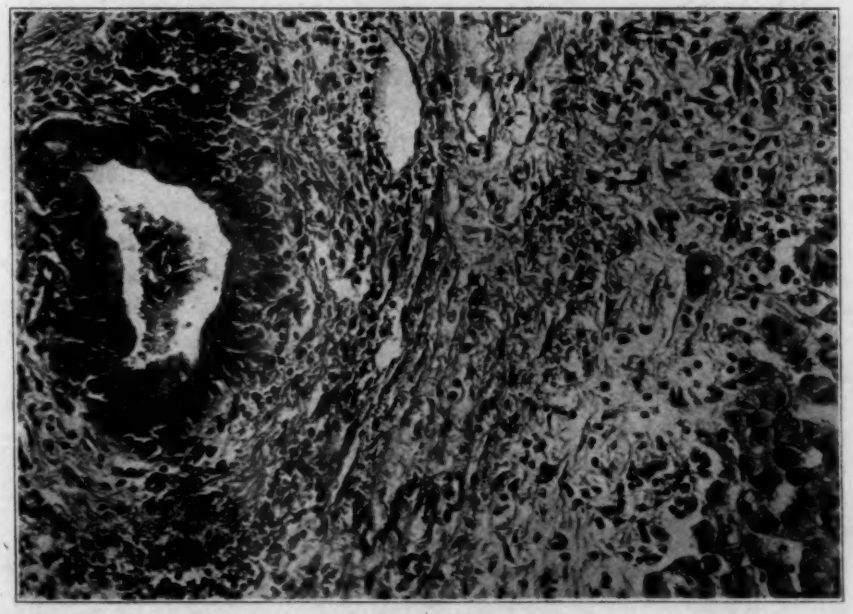

Fig. 1.—The photomicrograph showing a "true Luschka duct;" × 247. These ducts lie on the undersurface of the liver, between it and the gallbladder; they are lined by tall columnar epithelium and fail to empty into the lumen of the gallbladder. Luschka regarded them as metamorphosed rests of the primordium of the liver.

of the glands following obstruction. In his "Anatomie des Menschen," published in 1863,[7] he still maintained that the gallbladder has few glands but that they are never entirely absent. He then described what are called "true Luschka ducts," in which he was unable to find an opening into any space, and which he concluded were metamorphosed rests of the embryonal primordium of the liver (fig. 1).

7. Luschka, H.: Anatomie des Menschen, Tübingen, Lapp & Siebeck, 1863, vol. 2, p. 256.

Mueller,[8] in 1895, wrote that he had never observed glands in the normal gallbladder but that he had found them in great numbers in all gallbladders with stones. In his opinion, the mucus secreted by the glands is necessary for the formation of stones.

Létienne [9] in 1895 and Péraire [10] in 1903 and others reported finding stones within the wall of the gallbladder, and much discussion ensued as to how they got there. Many observers attributed their presence to ulceration, as they found no epithelium about the stones, while others believed that they were formed in mucous glands which were then closed.

It remained for Aschoff [11] in 1905 to clear up the situation by means of a study of 145 gallbladders, of which number 6 were free from stones. In this study he divided the wall of the gallbladder into five layers: the mucosa, the muscularis, the fibrosa, the subserosa and the serosa, of which only three layers are now recognized by the "Basle Nomina Anatomico," i. e., the mucosa, the muscularis and the serosa.

Aschoff failed to find any plasma cells in the wall of the normal gallbladder or any glands in the region of the fundus. He described interruptions in the muscularis occupied by blood vessels of varying size and stated that strong contractions of the gallbladder force the mucosa through these interruptions or clefts, so that it may extend to the tunica fibrosa. These observations are illustrated by beautiful colored photomicrographs. He gave credit for describing the sinuses to Luschka, but I shall show later how many disagree with him. In continuing his observations, he stated that in cases of stones an active growth of the mucosa may be seen which has extended beneath the muscularis, the "cholecystitis glandularis proliferans" of Boyd.[12] These sinuses hinder contraction of the wall of the gallbladder, contain cellular débris, inflammatory cells and crystals and act as niches for the formation of stones.

Aschoff contended, and for his contention I shall offer confirmatory evidence later, that an abundance of these Rokitansky-Aschoff sinuses is not the cause but the result of cholelithiasis, and, indeed, the result of increased pressure and the presence of stones complicated by infection. The sinuses constitute evidence of increased pressure; the gland

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8. Mueller, Friedrich C.: Zur pathologischen Bedeutung der Drüsen in der menschlichen Gallenblase, Inaug. Dissert., Kiel, L. Handorff, 1895.

9. Létienne, A.: Des calculs pariétaux, Méd. mod. **6**:529-531, 1895.

10. Péraire, M.: Calculs biliaires dans le canal cystique, Rev. de chir. **28**: 41-62, 1903.

11. Aschoff, L.: Bemerkungen zur pathologischen Anatomie der Cholelithiasis und Cholecystitis, Verhandl. d. deutsch. path. Gesellsch. **9**:41-48, 1905.

12. Boyd, W.: Surgical Pathology, Philadelphia, W. B. Saunders Company, 1933, p. 335.

formation indicates chronic infection. Such sinuses also play an active and important part in inflammatory processes and when filled with pus are apt to perforate.

Skikinami,[13] in 1908 said that Aschoff first described these glands and that Luschka knew them only superficially; that to Aschoff should go the credit for describing their origin and development. He stated that Rokitansky-Aschoff sinuses are diverticula in the epithelium of the mucosa and that they are therefore always connected with the lumen of the gallbladder, though the indentations may reach well into the tunica propria.

Again, in "Die Cholelithiasis"[14] Aschoff and Bacmeister gave Luschka all the credit for describing these sinuses, although they said that Skikinami was quite correct in stating that Luschka knew them only superficially. In this text are presented excellent drawings of intramural stones, which the authors contended were in Luschka's canals, although they were surrounded by fibrous tissue without a suggestion of mucosa.

Since Aschoff's original paper, there have been numerous reports of intramural gallstones. Rago[15] and Grasso[16] stressed their importance in relation to stones in the lumen; Grasso, in particular, emphasized the formation of intramural stones as a cause of cholelithiasis and presented diagrams to show stones being extruded into the lumen of the gallbladder.

Gosset and his co-workers[17] gave an excellent description of the formation of intramural stones, with five illustrative plates. They found the stones always located in the interior of Rokitansky-Aschoff sinuses and removed them easily with the aid of small forceps. According to their description, the stones are surrounded by closely applied mucosa, but at times a small amount of mucous secretion is interposed. About the sinuses there is usually cellular reaction consisting of plasma cells and lymphocytes and rarely of polymorphonuclear leukocytes. The adventitia is usually scarred and fibrosed. The authors lead one to believe that intramural stones occur without the presence of free stones in the lumen and may, in fact, cause them. They advocate cholecystectomy as the only treatment which offers a cure.

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13. Skikinami, J.: Beiträge zur mikroskopischen Anatomie der Gallenblase, Anat. Hefte **36**:554-597, 1908.

14. Aschoff, L., and Bacmeister, A.: Die Cholelithiasis, Jena, Gustav Fischer, 1909, p. 18.

15. Rago, G.: La calcolosi intramurale della cistifellea, Osp. maggiore **20**:453-464, 1932.

16. Grasso, R.: Considerazioni su di un caso di cistifellea a fragola e di calcolosi interstiziale, Policlinico (sez. chir.) **38**:335-350, 1931.

17. Gosset, A.; Duval, P.; Bertrand, I., and Moutier, F.: Les calculs vésiculaires intramuraux, Presse méd. **11**:161-164, 1930.

In a recent article Baroni [18] reported a case and discussed calculosis of the gallbladder with the production of calculi in the tissues of the organ without damage to the Rokitansky-Aschoff sinuses. In his opinion, the mechanism which produces calculosis is the same as that which causes "strawberry gallbladder," and he expressed the belief that the former constitutes the end-stage of this process (fig. 2).

The development of diverticula of the gallbladder arising from these sinuses is of interest in connection with this study. The subject was discussed by Vastine,[19] who reported 2 cases diagnosed by roent-

Fig. 2.—Photomicrograph showing proliferation of the mucosa of the gallbladder beneath the muscularis, while to the side and entirely separate is a large deposit of cholesterol crystals; × 68. These deposits are not surrounded by mucosa, but foreign body giant cells may be seen at the periphery. This condition has been described by Baroni (Arch. ital. di anat. e istol. path. **5**:76-96, 1934).

gen examination. He expressed the belief that the diverticula are the direct result of sinuses. I have had the privilege of studying the sections from 1 of his gallbladders. Rokitansky-Aschoff sinuses and a diverticulum were present, but the latter was not lined with mucosa as one would expect it to be were it the result of a sinus. The hypothesis may be advanced that the stone has ulcerated part way through the

18. Baroni, B.: Sulla genesi interstiziale dei calcoli nella cistifellea, Arch. ital. di anat. e istol. path. **5**:76-96, 1934.

19. Vastine, J.: Diverticulum of the Gallbladder, Am. J. Roentgenol. **31**:603-606, 1934.

wall, forming the diverticulum by destruction of the mucosa and muscularis.

In 1894 Weltz [20] reported 5 cases of diverticula, all of which seemed to have been small and within the wall of the gallbladder. In his first case he found large cavities in the wall, which apparently had no connection with the lumen; one, however, communicated with the lumen, and he considered this a diverticulum. In the second case he found stones in the wall of the gallbladder, but he was unable to trace any connection with the lumen. These 2 cases seem quite definitely related to Rokitansky-Aschoff sinuses; the other 3 probably are not so related, for in 1 the diverticulum was lined with muscularis and in the other 2 the mucosa was lacking.

Deaver and Ashhurst [21] reported a case in their textbook in which the gallbladder was full of stones of various sizes. The neck of the gallbladder, just above the junction with the cystic duct, was pouched out in such a way as to form a sac which pressed on the common duct and caused obstructive jaundice. Cholecystectomy was done, and stones were not found in the common duct. Rokitansky-Aschoff sinuses were not mentioned. In this case the sac may have been a dilated ampulla.

Bársony [22] reported the case of a 23 year old woman with a diverticulum the size of a hazelnut, located at the fundus of the gallbladder and lined with mucous membrane. The diverticulum was diagnosed by roentgen examination. At operation stones were not found in the gallbladder.

ORIGINAL WORK

In this study 300 gallbladders removed at operation have been examined. In the majority of cases two sections were taken from each specimen, one from the neighborhood of the fundus and the other from near the neck. Particular attention was paid to the presence or absence of Rokitansky-Aschoff sinuses.

In the normal gallbladder there is some invasion of the muscularis by mucosa, but so far no one has defined the dividing line between normal invasion and that type of herniation which has been called a Rokitansky-Aschoff sinus. As a result of this study, I have defined a Rokitansky-Aschoff sinus as a herniation or outpouching of the mucosa below or beneath the muscularis. Mucosal sinuses, lying entirely free beneath the muscularis and covered by intact muscle, are included in the definition, for serial sections show a communication between them and the lumen of the gallbladder.

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20. Weltz, H.: Ueber Divertikel der Gallenblase, Inaug. Dissert., Kiel, L. Handorff, 1894, pp. 5-20.

21. Deaver, J. B., and Ashhurst, A. P. C.: Surgery of the Upper Abdomen, Philadelphia, P. Blakiston's Son & Co., 1914, p. 42.

22. Bársony, T.: Divertikel der Gallenblase, Klin. Wchnschr. **7**:216-217, 1928.

With this as a standard definition, the 300 gallbladders were classified. In 101 (30 per cent) typical Rokitansky-Aschoff sinuses were found, while in 199 (60 per cent) they were absent.

The majority of writers have failed to stress the presence of gallstones as a factor in the formation of Rokitansky-Aschoff sinuses; rather, many of them have concluded that stones form in the sinuses, are extruded into the lumen and so give rise to gallstones in the gallbladder. Aschoff has, however, stressed the importance of gallstones

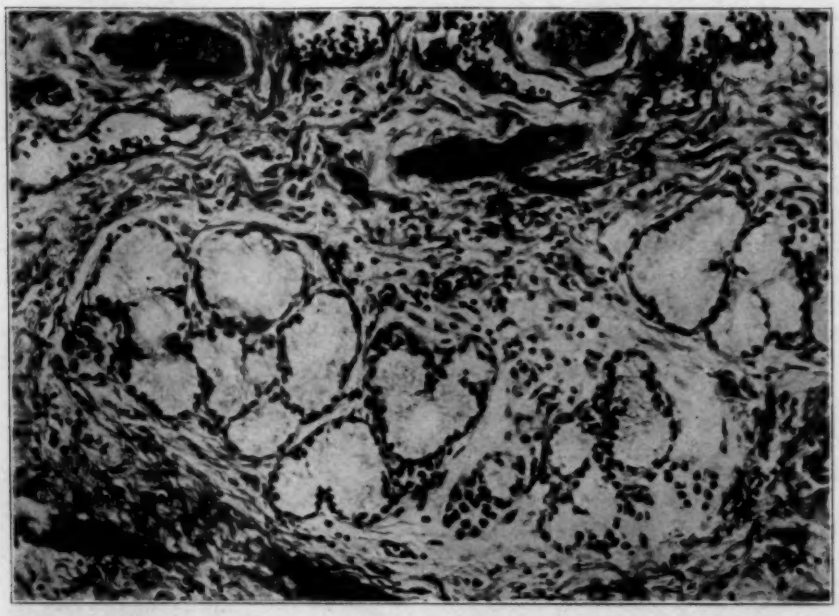

Fig. 3.—Photomicrograph showing a section from the neck of the gallbladder, with scattered muscular fibers; × 262. This is a true gland in the region in which such glands are usually found. Note the tall columnar cells filled with mucus, the nuclei being pushed to the outside or bottom of the gland. The best description of these glands in an English text is by Maximow (Textbook of Histology: True Ducts of Luschka, Philadelphia, W. B. Saunders Company, 1931, p. 551).

as an etiologic factor in the formation of these sinuses, and my study on this relationship may here be stated.

In the 300 specimens reviewed, stones were found in the gallbladder in 231, or 77 per cent, and not found in 69, or 23 per cent. Of the 231 gallbladders containing stones, 98, or 42 per cent, showed Rokitansky-Aschoff sinuses, and 133, or 58 per cent failed to show them. Of the 69 gallbladders free from stones, only 3, or 4 per cent, showed Rokitansky-Aschoff sinuses, and 66, or 96 per cent, failed to show them.

In the total of 101 gallbladders which showed Rokitansky-Aschoff sinuses, 98, or 97 per cent, contained stones, and 3, or 3 per cent, failed to contain stones. This would certainly substantiate Aschoff's original contention, if such substantiation were needed (fig. 3).

In figures 4, 5 and 6 the development of Rokitansky-Aschoff sinuses is shown. The mucosa invaginates or grows completely through the muscularis and expands in the subserosa, leaving a neck which communicates with the lumen of the gallbladder. The epithelium may proliferate extensively outside the muscularis, giving rise to the "chole-

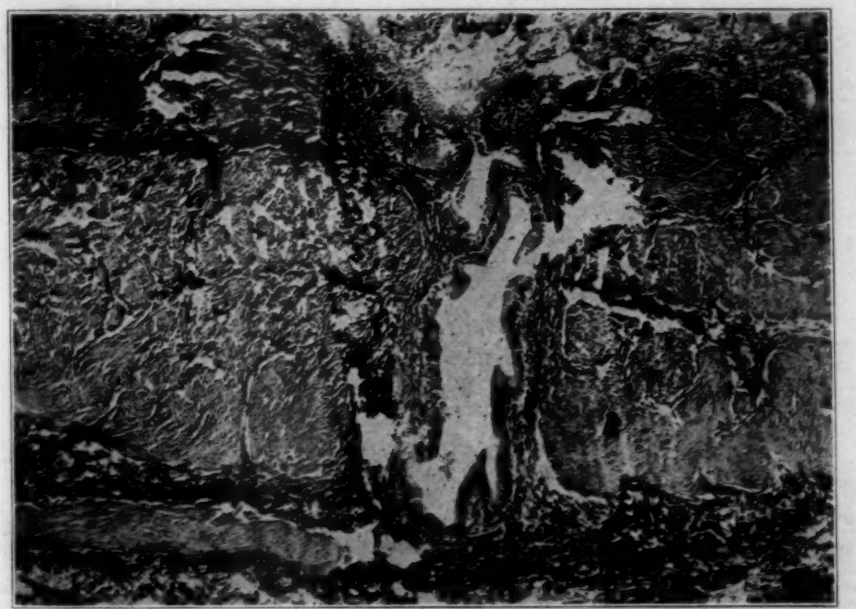

Fig. 4.—Photomicrograph showing the invasion of the mucosa to the lowermost level of the muscularis; × 59. This has been set as a minimum requirement for the designation of Rokitansky-Aschoff sinuses. The mucosa is connected with the lumen of the gallbladder and has penetrated the entire muscular layer of the wall. As can be seen, a small amount of connective tissue has been carried through the wall by the mucosa, while lymphocytes infiltrating the surrounding tissue can be seen. This mucosa is intact, whereas much of that in the lumen is desquamated.

cystitis glandularis proliferans" of Boyd, and may appear to be completely cut off from the cavity of the gallbladder (fig. 6). As asserted by Aschoff, there is a definite tendency for the evagination of the mucosa to occur at points where large vessels penetrate the muscularis, but this is not always true. Halpert,[28] who studied over 300 gall-

23. Halpert, B.: Morphological Studies of the Gallbladder, Bull. Johns Hopkins Hosp. **41**:77-103, 1927.

bladders removed at operation, found that the muscularis of the healthy gallbladder under ordinary conditions is dense enough to prevent outpouchings of the mucosa toward the external layer. He expressed the belief that the normal defects in this layer which serve for the passage of blood vessels may also occur independently and offer potential channels through which, under certain circumstances, the mucosa may protrude toward the external layer. He found that the presence of typical and numerous Rokitansky-Aschoff sinuses is usually associated with structural changes in the wall of the gallbladder, which may be

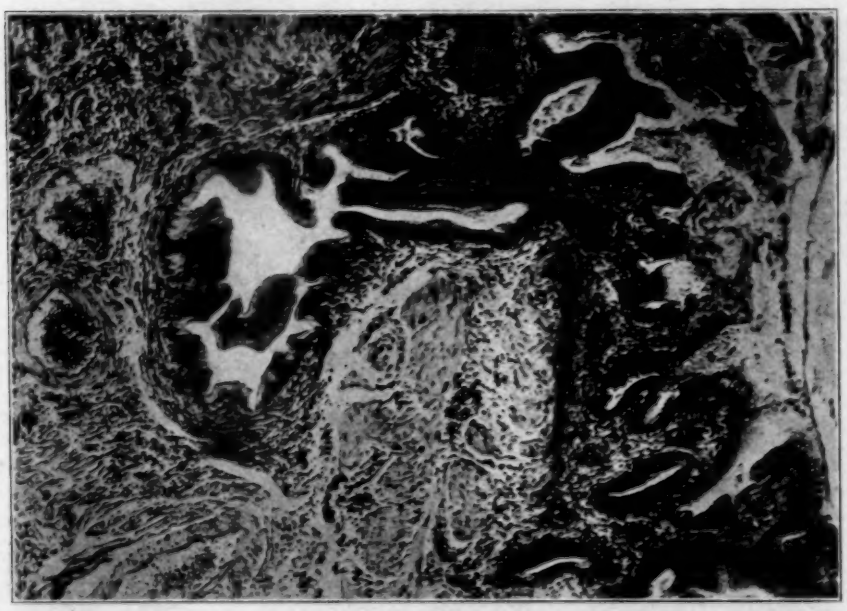

Fig. 5.—Photomicrograph showing the growth of the mucosa through the wall in the direction of the vessels; × 81. Two arteries with an accompanying thin-walled vein may be seen. These vessels appear to be attracting the mucosa. Notice again the increase of fibrous tissue and infiltration by lymphocytes about the sinus.

responsible for their formation. Most constant and conspicuous of these are the thickening of the wall of the viscus, due to the marked hypertrophy of the muscularis and increase of the connective tissue forming the perimuscularis and a varying degree of cellular infiltration in the subepithelial layer, the intermuscular septums and the perimuscular layer and especially around the fundi of the Rokitansky-Aschoff sinuses. In Halpert's article no mention is made of the relation of Rokitansky-Aschoff sinuses to stones or their incidence in the gallbladders studied.

The histories of all patients with gallstones in this series have been reviewed with regard to the length of time elapsing between the onset

of symptoms presumably due to a pathologic process in the gallbladder and the operation.

In the case of 98 gallbladders with stones and Rokitansky-Aschoff sinuses this period averaged forty-eight and fifteen hundredths months, or a little over four years. For the 133 gallbladders which showed stones but in which there were no Rokitansky-Aschoff sinuses, the average time from the onset of symptoms to operation was forty-seven and ninety-three hundredths months, or just short of four years. These facts seem to show conclusively that the duration of the disease has little or nothing to do with the formation of these sinuses.

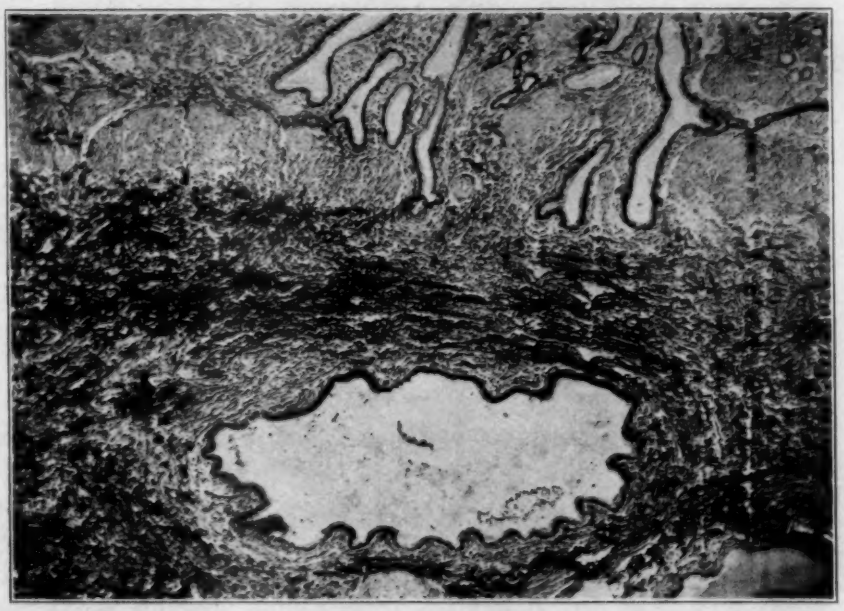

Fig. 6.—Photomicrograph showing the mucosa growing completely through the muscularis, beneath which is a large space lined by mucosa; × 48. This space appears to be cut off from the cavity of the gallbladder. In other sections this is found to communicate with the lumen. Note the dense connective tissue infiltrated by lymphocytes surrounding this area.

COMMENT

After the formation of a Rokitansky-Aschoff sinus, what may be its course?

1. It may remain stationary.
2. It may produce "cholecystitis glandularis proliferans."
3. It may develop into a diverticulum.
4. It may form an abscess and perforate.
5. Stones may form in its interior.

Owing to the large number of gallbladders in which these sinuses are found and the small number in which complications occur, it would seem that the large majority of sinuses remain stationary, or at least inactive.

Although fairly common, "cholecystitis glandularis proliferans" does not appear to lead to a serious pathologic process, though it may bear a relationship to carcinoma, which occurs almost entirely in gallbladders harboring stones.

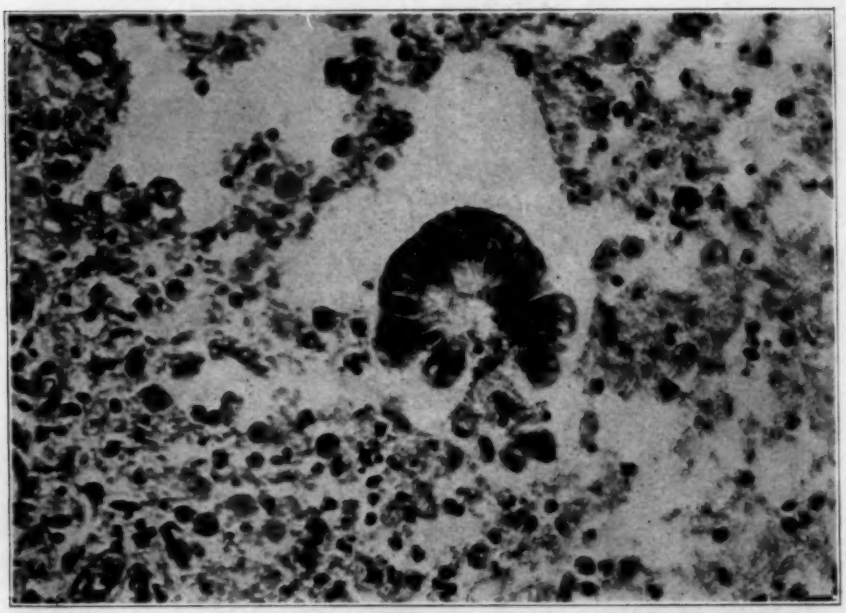

Fig. 7.—Photomicrograph showing a bit of well preserved mucosa of the gallbladder lying in an abscess which has formed entirely beneath the muscularis; × 350. In this gallbladder there were five abscess cavities lying in the wall. One had ruptured by means of a punched-out defect in the wall of the gallbladder beneath the liver and had formed an abscess there, while the others drained into the gallbladder. Rokitansky-Aschoff sinuses were present, and it seems that the inflammation started in these and developed into abscesses; all but one drained back into the gallbladder; the other perforated through the wall.

It has been stated that diverticula of the gallbladder occur in rare instances. In the opinion of some observers, they are the result of Rokitansky-Aschoff sinuses.

In his original article, Aschoff called attention to the presence of abscesses arising from the sinuses in the wall of the gallbladder and showed that there is much more inflammation surrounding the sinus than elsewhere in the wall. In 2 of our cases there was a small punched-out perforation in the wall without extensive damage elsewhere. In

Fig. 8.—Photomicrograph showing a stone lying in a Rokitansky-Aschoff sinus; × 30. Although the mucosa is largely desquamated, there is a sufficient amount left to show that the stone had been entirely surrounded by it. An opening may be seen leading into the lumen of the gallbladder. Such an opening has led various investigators to believe that stones formed in the sinuses and were extruded into the cavity of the gallbladder.

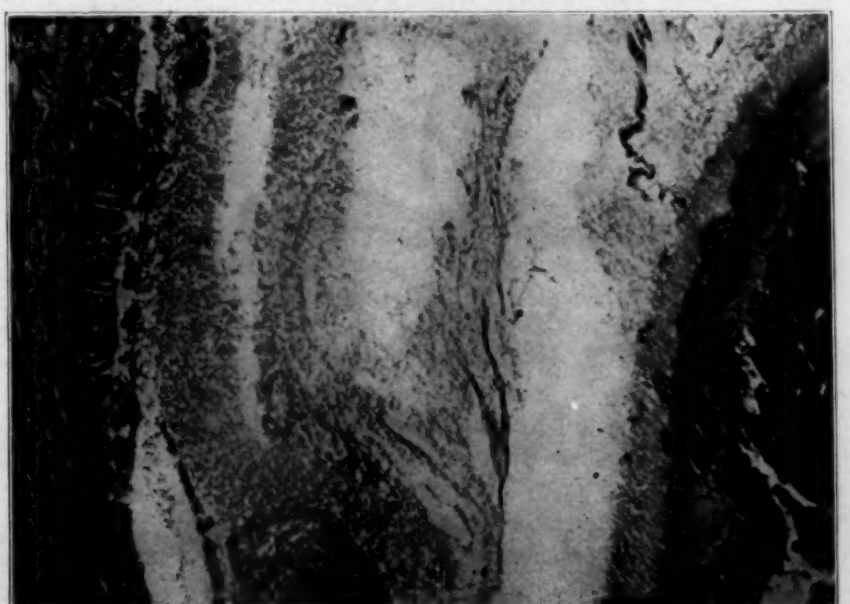

Fig. 9.—High power magnification of a section of the specimen in figure 8, to show the epithelium lining the sinus and its relation to the stone; × 219.

both cases, Rokitansky-Aschoff sinuses were found. In 1 the perforation had formed an abscess between the gallbladder and the liver, while in the wall of the gallbladder there were four other abscess cavities opening into its lumen. In one section (fig. 7) fragments of the mucosa of the gallbladder were present in the midst of purulent exudate. It would seem that in both of these cases perforation was secondary to an infection of the Rokitansky-Aschoff sinuses.

The formation of stones in the sinuses seems less important than abscess formation and perforation. In several instances, granular and cellular débris and bile pigments have been found in the sinuses; 1 gallbladder in the series which contained 40 black faceted stones in its lumen showed many small concretions, from 2 to 4 mm. in diameter, embedded beneath the mucosa (figs. 8 and 9). On section these stones appeared to be composed of inspissated bile pigments. They lay in Rokitansky-Aschoff sinuses, which were lined with cuboidal epithelium. Around the stones there was mucinous material, and outside the sinus, marked infiltration of lymphocytes.

SUMMARY

Stones within the wall of the gallbladder were first described by Morgagni and later by Rokitansky, who found them in small outpouchings in the mucous membrane of the wall. These sinuses were first studied and described in full by Aschoff. They are known as Rokitansky-Aschoff sinuses. Aschoff also called attention to stones in the sinuses, to the marked infection which may surround them and to abscess formation and perforation which may occur. He advanced the theory that the sinuses are the result of increased pressure and stones within an infected gallbladder. Many observers since Aschoff have reported these sinuses, but for the most part they have failed to associate their presence with stones in the gallbladder; some have even considered them the cause of cholelithiasis. They also have been believed to be factors in the development of diverticula, and their multiplication under the muscularis is defined as "cholecystitis glandularis proliferans."

Rokitansky-Aschoff sinuses have been accurately defined, and a report is made on 300 gallbladders removed at operation and studied by me. Of this number 231, or 77 per cent, contained stones, while 101, or 30 per cent, showed Rokitansky-Aschoff sinuses. Of the 101 gallbladders in which sinuses were found, 98, or 97 per cent, contained stones.

Two cases are described in which the gallbladder had perforated; in both of these, Rokitansky-Aschoff sinuses were present and were thought to have played a part in the perforation. One case is reported in which there was formation of stones inside the sinuses, lying deep beneath the muscularis of the gallbladder.

CONCLUSIONS

Rokitansky-Aschoff sinuses are found to be not uncommon when the walls of gallbladders are studied microscopically.

The sinuses are the result of cholelithiasis and secondary infection rather than the cause of gallstones.

Rokitansky-Aschoff sinuses may give rise to local abscess formation in the wall of the gallbladder. The abscesses may drain into the lumen or perforate through the wall of the gallbladder.

Stones may form within the sinuses, and at operation they will be found to lie under the muscularis.

DRAINAGE OF CEREBROSPINAL FLUID IN THE TREATMENT OF ACUTE HEAD INJURIES

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The treatment of acute head injuries has recently become of increasing importance, owing primarily to the increasing incidence of the disease and secondly to the prevalence of the postconcussion syndrome, particularly in cases in which the patient is seeking compensation.

Much has appeared in the literature on treatment, and in regard to most points the authors agree. Concerning rest, sedatives, the application of ice to the head and the restriction of fluid, there is little disagreement.

However, regarding the use of spinal puncture and the indications for surgical intervention, there have always been differences of opinion among neurosurgeons and confusion in the minds of the general surgeons, who see most of the patients with such injuries. There have always existed differences of opinion regarding the use of spinal puncture and surgical treatment in cases of head injury, but recently there has been more confusion by the appearance of articles of wide-reaching influence (Dandy [1]) in which the use of both spinal puncture and the administration of hypertonic solutions intravenously is strongly deplored and the impression is given that little is to be done for the patient other than to prescribe rest, operation being reserved for the small group (10 per cent) who do not die immediately and who fail to respond favorably to rest alone.

I propose to show in this article that much can be done in the treatment of patients with acute head injuries, including those with only mild concussion, and particularly that drainage of cerebrospinal fluid, both by lumbar puncture and by subtemporal trephine, but especially by the former method, is not only without danger but highly beneficial.

Clinical, pathologic and surgical observations all point to an increase of intracranial pressure as the outstanding finding in cases of cerebral concussion and to an excessive secretion of the cerebrospinal fluid as the principal factor causing this pressure. It would therefore seem reasonable that the most logical and convenient method of decompression or of returning intracranial pressure to normal would be drainage of the cerebrospinal fluid. This may be done in two ways: (1) by

1. Dandy, W. E.: Diagnosis and Treatment of Injuries of Head, J. A. M. A. **101**:772 (Sept. 2) 1933.

repeated spinal puncture and (2) by subtemporal trephine or decompression with drainage. The former method is by far the most frequently used; the latter is indicated in less than 10 per cent of the cases. Cisternal puncture is a more dangerous procedure and has little advantage over lumbar drainage.

It is decompression by drainage of the cerebrospinal fluid to which I would first direct attention. I first used this procedure with caution, in view of the consensus of many authors that spinal puncture is dangerous in states of increased intracranial pressure. However, it was reasoned that there should be no herniation of the medulla and cerebellum when the increased pressure is due to a fluid mass which could be drained around the brain stem through the basilar cisterns. This supposition was borne out clinically in a study of over five hundred punctures by the frequent and prompt relief of pressure symptoms after spinal puncture and the total absence of any untoward results.

Fourteen patients were subjected to craniotomy for the purpose of removing clots or fluid; on these, preoperative and postoperative spinal punctures were done, and the underlying pathologic process was determined at operation or at autopsy.

In the series of cases reported herewith, spinal puncture was done on every patient having sustained any degree of concussion who was having even minor pressure symptoms, i. e., headache, nausea, vomiting, stupor or coma, particularly if there was an associated bradycardia. The puncture was repeated every twelve to twenty-four hours as the symptoms indicated; in the average case it was repeated every day until the initial pressure was approximately normal (from 80 to 150 mm.); in the more serious case associated with deep coma or severe and unrelieved headache and vomiting, drainage was repeated as often as every six to eight hours.

The clinical results will be described later. Briefly, there was definite improvement in all symptoms after the first few punctures and frequently after the first puncture. On the whole, headache disappeared even before the pressure became normal; consciousness and rationality returned in most cases when the pressure became normal. In every case (with one exception) there was progressive clearing of the bloody fluid. Frequently, before the pressure had returned to normal, the spinal punctures were discontinued for some reason. I choose to call this period in which no drainage was done the "no drainage interval." The patients nearly always suffered a return of pressure symptoms, and on subsequent puncture the pressure would be found secondarily elevated. I choose to call this elevation the "secondary rise." Occasionally, on the first puncture, particularly if done early, the pressure would be approximately normal, but after several days without

spinal punctures pressure symptoms would develop, and on the next puncture the spinal pressure would be high; subsequently, the symptoms were relieved by drainage.

Occasionally a patient would continue to have high pressure and unrelieved symptoms even after repeated drainage. I choose to call this type of pressure "sustained pressure." In these cases it was assumed that there were accumulations of fluid subdurally (extra-arachnoid) which were loculated and could not be drained through the subarachnoid system. Here surgical measures were indicated for drainage of the loculated fluid. However, the same overproduction of cerebrospinal fluid continued, and further spinal punctures were necessary to control the pressure after the drainage of fluid subtemporally had ceased and the wound had healed.

After carrying out this treatment in about one hundred and forty cases of head injury without any guide other than the patient's clinical signs and symptoms, it was found that the clinical course closely paralleled the degree of pressure of the intracranial fluid, as shown by the curves for the spinal fluid pressure. The curves formed by these initial pressures fell into three well defined types: (1) a progressive fall in pressure, (2) a secondary rise in pressure after a "no drainage interval" and (3) sustained pressure.

The excellent results and the freedom from complications obtained in this series of patients by the use of spinal puncture compared with the adverse criticism of this procedure in the recent literature makes it obvious (1) that either there is or there is not a place for lumbar drainage in at least certain selected cases; (2) that the question is vitally important, if the surgeon is to have a clear idea of the treatment of head injuries, and finally, (3) that the solution of the problem should be based on clinical observations and findings in a sizable group of cases.

The points to be considered are: drainage by spinal puncture, its dangers, diagnostic value and therapeutic value, and drainage by subtemporal decompression, its indications, and preoperative and postoperative spinal drainage.

REVIEW OF THE LITERATURE

A perusal of the literature will emphasize the discord which exists even among reputable neurosurgeons.

SPINAL DRAINAGE

Dangers.—Dandy [2] stated that "in the presence of intracranial pressure from whatever source, lumbar punctures are always dangerous."

2. Dandy, W. E.: Treatment of Acute Intracranial Pressure, in Lewis, Dean: Practice of Surgery, Hagerstown, Md., W. F. Prior Company, Inc., 1932, vol. 12, chap. 1, p. 284.

On the other hand, Grant [3] said that he had "never seen properly performed lumbar puncture have any ill effect," and Jackson [4] expressed the belief that the "danger of lumbar puncture in these acute traumatic cases has been greatly overestimated." According to Jaeger [5]: "This method of treating brain injuries is too dangerous—its possible good effects being far outweighed by the harm it can do by medullary compression and trauma." On the other hand, Bagley [6] stated that "when there is an excess of cerebrospinal fluid, a lumbar puncture is not dangerous but offers relief." Furthermore, Morrissey [7] and Towne [8] both mentioned the safety and desirability of doing early and repeated spinal drainage. McCreery and Berry [9] said: "We believe that this danger has been over-emphasized and that the advantages to be gained—both diagnostically and therapeutically—outweigh the risks."

There are those who use lumbar puncture but still have some question regarding the danger. Rand and Nielsen [10] reported that they have had no untoward results from lumbar puncture, yet they watch the pulse and the general condition of the patient closely. McKenzie [11] advised slow withdrawal of fluid but stated that it is possible to remove too much fluid and so bring about herniation of the medulla and cerebellum into the foramen magnum. Naffziger [12] said that a direct reading of the intracranial pressure by the spinal fluid manometer was often impracticable owing to the frequency of irritability, restlessness and lack of control of the patient. Cairns [13] stated that lumbar puncture "is open to the objection that it disturbs the patient

3. Grant, F. C.: Treatment of Cranial Trauma, S. Clin. North America **5**: 1537 (Dec.) 1925.

4. Jackson, Harry: The Management of Acute Cranial Injuries by the Early, Exact Determination of Intracranial Pressure, and Its Relief by Lumbar Puncture, Surg., Gynec. & Obst. **34**:494, 1922.

5. Jaeger, J. R: Treatment of Injuries to Skull and Brain, Colorado Med. **28**:348, 1931.

6. Bagley, Charles, Jr.: Blood in Cerebrospinal Fluid: Resultant Functional and Organic Alterations in Central Nervous System; Clinical Data, Arch. Surg. **17**:18 (July) 1928.

7. Morrissey, E. J.: Head Injuries: Their Treatment, California & West. Med. **35**:198, 1931.

8. Towne, E. D., in discussion on Morrissey.[7]

9. McCreery, J. A., and Berry, F. B.: A Study of Five Hundred and Twenty Cases of Fracture of the Skull, Ann. Surg. **88**:890, 1928.

10. Rand, C. W., and Nielsen, J. M.: Fracture of the Skull: Analysis of One Hundred and Seventy-One Proved Cases, Arch. Surg. **11**:434 (Sept.) 1925.

11. McKenzie, K. G.: The Management of Cranio-Cerebral Injuries, Univ. Toronto M. J. **6**:215 (May) 1929.

12. Naffziger, H. C.: Head Injuries: Indications for Surgical Treatment, S. Clin. North America **3**:699, 1923.

13. Cairns, Hugh: Treatment of Head Injuries: II. Conservative and Operative Measures, Lancet **1**:617 (March 24) 1928.

considerably, and for this reason, whenever possible, the use of hypertonic salt solutions is to be preferred."

There is also confusion concerning the degree of intracranial pressure in which puncture is indicated. Sharpe [14] stated that it is only for patients having a mild increase of intracranial pressure that this method should be advocated as ". . . patients having a high increase of intracranial pressure (over 16 mm. of mercury) should not be subjected to the risk for fear that this high intracranial pressure would force the medulla into the foramen magnum. . . ." Peet [15] stated that although there was danger of increasing hemorrhage, he did use the method early in cases of acute involvement to protect the medulla! It is no wonder that surgeons are confused with such conflicting statements in the literature.

Diagnostic Value.—As a diagnostic measure, the advisability of the use of lumbar puncture is still undecided. According to Dandy [2] spinal punctures do not yield any information of value in diagnosis and the information obtained by carefully studying the patient's signs and symptoms is far better and at the same time is more safely secured. He also stated that spinal puncture and the injection of dextrose intravenously are contraindicated and may cause serious harm. Coleman [16] wrote: "We have used spinal puncture guardedly in the examination of patients with acute brain injury severe enough to require treatment directed to the intracranial condition." The proper use of spinal puncture gives added information, not supplied clinically, as to the degree of intracranial pressure.

McCreery and Berry [9] stated that were it not for the information gained by spinal tapping some patients, whose injury was relatively slight and whose symptoms were evanescent, would be thought to have merely a mild concussion.

Therapeutic Value.—As a therapeutic measure, the discussion of lumbar puncture occupies the center of the stage. Dandy [2] stated: "How certain is it that there may not be adverse effects, either immediate or remote . . .? On the next puncture the period of relief may be shorter and each succeeding puncture has less, and finally no effect; . . . spinal punctures and intravenous injections of hypertonic glucose or sodium chloride are contra-indicated in efforts to reduce

14. Sharpe, William: Diagnosis and Treatment of Brain Injuries, Philadelphia, J. B. Lippincott Company, 1920, p. 81.

15. Peet, Max M.: Reduction of Increased Intracranial Pressure by Intravenous Administration of Glucose and Hypertonic Ringer's Solution, J. A. M. A. **84**:1994 (June 27) 1925.

16. Coleman, C. C.: The Management of Acute Brain Injuries, J. A. M. A. **97**:1696 (Dec. 5) 1931.

the intracranial pressure. They may cause serious harm." Wilensky [17] said that "spinal puncture has not given complete satisfaction as a therapeutic measure and that "the ultimate result has not differed from that obtained when no such procedure was used." Naffziger [12] stated that "in the face of rapidly advancing signs of pressure spinal puncture is inadequate." Glaser,[18] in a discussion of Morrissey's article, said: . . . I have reduced the use of spinal puncture to a minimum. . . . In my experience, cases do well without this form of treatment." On the other hand, Adson [19] expressed the belief that if other measures fail to reduce the pressure "spinal puncture should be performed every eight to twelve hours." According to Cairns,[13] the fluid should be withdrawn slowly; while Coleman [16] stated that spinal puncture is of more value as a test for pressure than as a therapeutic measure.

Other writers have been enthusiastic concerning the use of spinal punctures as a therapeutic measure. McCreery and Berry [9] stated: "In the more severe cases repeated spinal taps have been the most valuable method of treatment. Henry [20] reported the use of repeated spinal punctures "in the absence of coma, focal signs or obvious fracture. . . . this is repeated in four, eight or twelve hours, and as often as deemed necessary to keep the pressure down to normal for several days." He further stated that ". . . operation has been done much less frequently since adopting this measure. . . ." Jackson [4] also reported the uses of this measure. He stated: "The relief of increased pressure on the brain and the re-establishment of the normal path of absorption of the cerebrospinal fluid can be obtained by repeated lumbar drainage." Mock expressed the belief that the mortality has decreased with the use of lumbar drainage and the injection of hypertonic solutions. Johnson [21] also reported the use of repeated punctures.

Rand and Nielsen [10] said that drainage of cerebrospinal fluid is often resorted to as a therapeutic measure, especially in cases in which the pressure is increased, and that those patients in whom headache is relieved may be benefited if this procedure is repeated. They stated: "It appears that more prompt relief is obtained from repeated lumbar puncture than from other methods."

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17. Wilensky, A. O.: The Neurologic Manifestations of Fracture of the Skull (Craniocerebral Injuries), S. Clin. North America **1**:1709, 1921.

18. Glaser, in discussion on Morrissey.[7]

19. Adson, A. W.: Treatment of Injuries to the Head, Internat. J. Med. & Surg. **43**:617, 1930.

20. Henry, C. K. P.: Cranial and Intracranial Injuries, Canad. M. A. J. **15**: 913, 1926.

21. Johnson, L. W.: Treatment of Head Injuries, U. S. Nav. M. Bull. **29**: 592, 1931.

Drainage of Bloody Fluid.—Rand and Nielsen [10] found blood in the cerebrospinal fluid of 85 per cent of patients with fractures, and Werden [22] found the same percentage in all patients with concussion.

That the cerebrospinal fluid contains blood which is irritating to the meninges and may cause additional pressure there is no doubt. However, here again writers differ on the treatment of traumatic hemorrhage in the subarachnoid system. Dandy [2] has been the most emphatic in stating that the additional space afforded by drainage permits renewed bleeding and that the only hope of cessation of hemorrhage is by compression of the brain against the bleeding point. Coleman [16] said that it is doubtful if any considerable amount of blood can be removed by spinal puncture, and Bagley [6] stated that occasionally the fluid became more bloody and that there was a question if lowering the pressure did not precipitate more hemorrhage, although in another article he said that bloody fluid can be drained by repeated puncture and that subtemporal drainage is advisable in the majority of cases and absolutely necessary in some. Peet [15] said that there was danger of increasing the hemorrhage but that he did use spinal puncture early in cases of severe involvement to protect the medulla. Rand and Nielsen [10] said that patients with bloody spinal fluid present signs and symptoms of meningitis, which disappear after the blood had been absorbed or drawn off by repeated punctures.

Surgical Drainage.—Even more has been written concerning subtemporal decompression in cases of head injury. It goes without saying that extradural and subdural hematomas are definitely surgical lesions. In this article I am interested in subtemporal decompression only from the point of view of establishing drainage in cases of increased intracranial pressure from excessive subdural and subarachnoid free fluid. The literature on this point is in considerable variance and discord, and even Dandy [23] stated that "it is here that the greatest differences in treatment are in vogue." It is his contention that no patient with a head injury, aside from one with extradural hematoma, should have treatment other than rest until he recovers spontaneously or the intracranial pressure increases to such a point that there is medullary decompensation and death is impending. He further stated that signs of this advancing medullary failure are deepening coma, restlessness, involuntary micturition or defecation and an increase in the temperature, and pulse and respiratory rates. Opposing this point of view, Jackson [4] stated that to wait for these signs before intervention is to court disaster.

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22. Werden, D. H.: Craniocerebral Injuries: Study of One Thousand Two Hundred Cases, California & West. Med. **37**:226, 1932.

23. Dandy.[1, 2]

Of particular note, and expressing a view to which I take exception, is the statment of Dandy: "During the period of bradycardia there is usually no need for action. With the onset of the above signs of medullary failure, subtemporal decompression is indicated; this occurs in about 10 per cent of all cases. Another group of 20 per cent will succumb regardless of what is done." Thus there remains a group of patients, comprising 70 per cent of those with head injuries, for whom nothing is done to relieve the pressure. It is toward those patients for whom no treatment is supposedly indicated and those in whom signs of medullary failure are eminent that I would most earnestly direct attention.

A further perusal of the literature regarding surgical treatment for head injuries will give a better understanding of the subject. Jackson [4] stated: "Lumbar drainage is superior to subtemporal decompression in relieving pressure below the tentorium cerebelli, and has the further advantage that it leaves no mutilating skull defect." He further stated that in experiments on dogs with increased pressure it is shown that pulse, respiration and blood pressure are affected only when the medulla is compressed and that "to wait for these changes as an indication for operation on the cerebrum in acute cranial injury is to court disaster." Rand and Nielsen [10] wrote: "Occasionally we have resorted to decompression when the patient was exceedingly irritable and disoriented, provided lumbar puncture and dehydration had failed to give relief." Naffziger [12] expressed the belief that for the edematous brain, decompression is not satisfactory, for fluid must be removed in order to give relief, but he further added that in the face of rapidly advancing signs of pressure, spinal puncture is inadequate, and a dextrose solution is of no demonstrable value. Coleman [16] reported the use of both spinal puncture and subtemporal decompression, but he appeared to favor the latter. He stated: ". . . so far as I know it has never been asserted that the repeated removal of spinal fluid at lumbar puncture and the administration of hypertonic solutions and magnesium sulphate will maintain continuously a lowered pressure," and "palliative measures . . . cannot be substituted for subtemporal decompression with drainage in all cases of brain injury."

Towne also reported the use of both procedures. He stressed particularly trephining for the drainage of subdurally trapped fluid and stated that he did not hesitate to do an exploratory operation in cases in which the differential diagnosis between cortical laceration and hemorrhage is difficult.

After having cared for three thousand, five hundred patients with head injury, I am convinced that decompression by repeated lumbar

punctures is definitely of value in a large majority, other than those with localized hematoma; that spinal drainage is indicated both preoperatively and postoperatively for those on whom surgical treatment is used (except those with hematoma) and finally that both spinal drainage and earlier surgical intervention are imperative for the group of 10 per cent (Dandy) in whom medullary failure is eminent. It is hoped that the following case reports will substantiate this contention.

SPINAL DRAINAGE

INDICATIONS

In this communication spinal drainage is not being offered as a universal remedy for cerebral concussion. It is offered as an adjunct to other equally important measures, of which little more than mention will be made in this article. Drainage of cerebrospinal fluid is stressed because it is this measure concerning which there is so much difference of opinion.

Contraindications will be discussed, but barring these, it may be said that drainage of cerebrospinal fluid is indicated in nearly every patient with concussion who shows (1) signs or symptoms of cerebral pressure, (i. e., varying degrees of coma, headache, nausea or vomiting, bradycardia and continued high cerebrospinal fluid pressure)—this holds also for postsurgical drainage—and (2) signs of meningeal irritation (i. e., cervical anteroposterior rigidity and continued bloody spinal fluid). Surgical drainage is indicated in patients who are not progressing well under spinal drainage, and it should not be delayed too long after the indications present themselves.

CONTRAINDICATIONS

There are certain well defined contraindications to lumbar puncture. Obviously the first is initial shock which follows injury. The next is extradural (arterial) hemorrhage. There is a tendency for this bleeding to be spontaneously retarded by pressure from cerebral edema. However, this pressure is often slight owing to the fact that blows which produce laceration of the middle meningeal artery are often minor and cause little cerebral damage and resultant edema. In any event, even marked cerebral pressure is almost never sufficient to control arterial bleeding. Spinal puncture is therefore contraindicated in that it lessens this retarding pressure.

The other less positive contraindication is compound fracture of the skull. If the fracture is in the vault, it is a depressed fracture subjacent to laceration of the scalp. Such a fracture does not positively contraindicate spinal drainage, but if the intracranial pressure is not endanger-

ing life it is better to postpone drainage until arachnoidal adhesions have walled off the potential entrance of infection. If the compound fracture is in the base (as are nearly all fractures which give rise to ecchymotic orbital lids, epistaxis, nasal cerebrospinal rhinorrhea, aural bleeding and cerebrospinal otorrhea, and perhaps also those which give rise to Battle's sign), it is again possible that drainage of cerebrospinal fluid may tend to diffuse infection from these sources into the subarachnoid system.

Continued drainage of cerebrospinal fluid from the nostrils and external auditory canals may so spontaneously decrease intracranial pressure that the patient is relieved of symptoms, and lumbar drainage does not become necessary. On the other hand, should pressure symptoms persist, even with rhinorrhea and otorrhea it may be that continued intracranial pressure is keeping the compound fracture and arachnoid tears open, in which case cautious and slow drainage of the spinal fluid would be indicated to assist in decreasing the pressure and hasten closure of the wound by arachnoidal or dural adhesions.

Some writers would include subdural hematoma among the contra-indications to spinal puncture on the basis that medullary herniation would result. It is my experience that patients with subdural hematoma do not collapse after spinal drainage but in fact are temporarily much improved. This is reasonable in view of the fact that a fluid mass such as hematoma, when acute, arises from venous bleeding, which soon ceases, and when subacute or chronic, increases in size either from slow capillary bleeding or by osmosis of free spinal fluid. Therefore, when either acute or chronic, release of pressure cannot increase the size of the mass. Furthermore, there is frequenlty a diffuse sub-arachnoid and extra-arachnoid excess of free fluid accompanying the hematoma. When puncture is done, this fluid is drained around the brain stem, thus preventing medullary herniation. However, given a patient in profound coma with slow pulse and stertorous respiration already showing signs of medullary herniation and impending collapse, fluid may not be able to flow around the brain stem, and puncture would obviously be fatal. In such a case caffeine and a 50 per cent solution of dextrose injected intravenously and immediate trephining to establish drainage would be the only recourse.

SPINAL PUNCTURE FOR DIAGNOSIS

I agree with other writers that in many instances spinal puncture is not necessary to diagnose the presence of intracranial pressure and that its presence can be suspected by the clinical signs. However, there are cases in which the signs and symptoms were not present, yet on puncture the pressure was high. These are the cases in which as a rule

no treatment is given, but in which treatment should be continued to abort later pressure symptoms and sequelae.

On the other hand, I have seen occasional cases of profound coma from cortical lacerations in which for some reasons cerebral edema and an increased secretion of cerebrospinal fluid did not result and the spinal pressure remained normal. It is obvious that in these cases, though coma and even localizing signs persisted, surgical intervention would have been urged had not low spinal fluid pressure shown that a surgical, pressure-producing lesion did not exist.

The following case reports show that clinical improvement parallels pressure and that an elevated pressure calls for successive punctures until the pressure persistently remains normal or until a surgical lesion is successfully treated.

TECHNIC FOR SPINAL PUNCTURE

Punctures were done with the patient flexed in a horizontal posture. A 1 per cent solution of procaine hydrochloride was used locally in the skin and deep fascia and an 18 gage needle was employed. As soon as fluid was encountered, a glass adapter was inserted; this in turn was attached by 4 cm. of soft rubber tube to a straight glass tube with a 1 mm. bore, measuring from 450 to 500 mm., and marked at intervals of 50 mm. Usually but 0.5 to 1 cm. of fluid was lost during the connection. Fluid was allowed to run to the end of the manometer leveled into the horizontal or inclining position. The manometer was raised to the vertical position, and the initial pressure was taken; readings were made after the withdrawal of each 4 to 6 cm. of fluid. If no changes were observed in the pulse rate or quality and no complaints were elicited from the patient, the pressure was lowered to from 50 to 100 mm. regardless of the amount of fluid required. The final pressure and the total amount of fluid removed were observed and recorded together with its color and appearance, and after standing from twelve to twenty-four hours, the percentage of blood by volume.

GROUP A: PROGRESSIVE FALL OF PRESSURE

The largest group of patients (group A) was composed of persons in whom there was an average progressive fall in cerebrospinal fluid pressure on each successive puncture (charts 1 to 4). The group illustrates the course in the average patient who is adequately treated and the desired end-result to be obtained by such treatment. The patients in this group appeared to have fewer pressure symptoms, complications and sequelae and a shorter duration of illness. The average of the initial pressures found on the first punctures was 324 mm., while the average of the initial pressures obtained on the last puncture done was 167 mm., showing a definite decline to approximately normal during the course of treatment. That there was a corresponding improvement in clinical symptoms will be shown later.

There were twenty-nine patients in this group who had from three to eleven punctures each (average five). They were divided into (1) those in whom drainage was started early (within one or two days of the injury) and (2) those in whom treatment was delayed for from four to eight days.

Subgroup 1: *Drainage Early, First or Second Day.*—There were twenty-one patients in whom spinal drainage was done within the first or second day after injury and repeated nearly every day until the final pressure was within normal limits. In all patients the initial puncture showed a high pressure; in nearly every case there was a progressive decline in pressure on each succeeding puncture. There was often marked improvement in the degree of consciousness or in the severity of pressure symptoms after the first drainage, and in every case there was definite

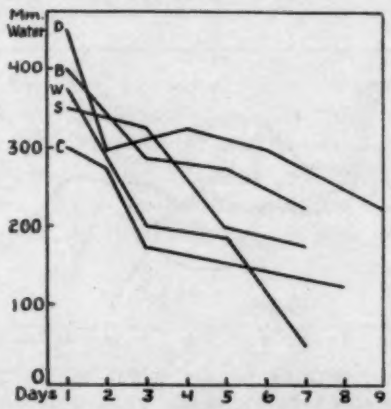

Chart 1.—Curves (designated by the initial of the patient) showing the progressive fall in the spinal fluid pressure of patients on whom drainage was done within the first or second day after injury. *S* indicates the curve for the patient in case 2.

improvement by the time the pressure had approximated normal. With one exception it was possible to control headache, so that by the time the patient was ready for discharge in from ten to fifteen days he was entirely free from symptoms. In the one exception, although the pressure decreased, coma persisted, and a subtemporal drainage was necessary.

The following cases (charts 1 to 3), with findings arranged so as to give the dates of symptoms, the initial spinal fluid pressure, the amount of fluid removed and the condition of the fluid, are representative of the group.

CASE 1.—A man aged 40 was injured on July 29, 1932, and was admitted to the hospital four hours later in coma. Examination revealed a laceration of the

scalp, hemorrhage from the canal of the right ear, cervical rigidity, bilaterally positive Babinski signs and a fracture of the skull in the right occiput.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
7/30/32	Coma	400	55	Bloody
	After first puncture patient immediately became conscious and rational	450	90	Bloody
7/31/32	Conscious	225	60	Bloody
8/ 1/32	Conscious	200	55	Yellow

Coma and high spinal fluid pressure persisted for three days. After the withdrawal of 90 cc. of fluid consciousness returned; the patient became rational and was without complaints.

Case 2.—A man aged 26 was injured on March 26, 1933, when his horse fell on him. He was unconscious for ten minutes and not entirely mentally clear until

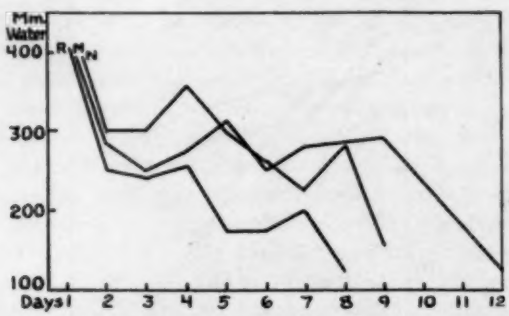

Chart 2.—Curves (designated by the initial of the patient) showing the progressive fall in the spinal fluid pressure of patients on whom drainage was done within the first or second day after injury. *M* indicates the curve for the patient in case 6, and *N* the curve for the patient in case 4.

after he was admitted to the hospital. Examination revealed ecchymosis of the lids of each eye, epistaxis and crepitus over the right antrum. The skull was fractured in the left occiput.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
3/27/33	Patient was confused; complained of headache; severe headache disappeared 30 min. after spinal puncture; did not return for two days, although high spinal fluid pressure continued; conscious	350	30	Bloody
3/28/33	Conscious	325	30	Blood tinged
3/29/33	No complaints	200	16	Blood tinged
3/30/33		160	15	Blood tinged

The patient's confused mental state and severe headache, which had been present for twenty-four hours, were promptly relieved after the first spinal drainage. There were no complaints after the spinal fluid pressure remained below 200 mm.

CASE 3.—A Mexican boy aged 7 years was struck by an automobile on Jan. 11, 1933. The duration of coma was unknown. Examination on his admission to the hospital showed stupor, cervical rigidity, tortuous retinal veins and filling of the optic cups.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
1/12/33	Stupor; vertigo			
1/13/33	Headache	320	14	Bloody
1/14/33	Less headache	370	15	7% blood
1/15/33	Still headache	220	14	4% blood
1/17/33	Felt better and wanted to go home	175	4	Slightly bloody

The headache was less after the second spinal drainage. The patient was much improved when the spinal fluid pressure was reduced to 175 mm. There was progressive clearing of blood from the cerebrospinal fluid.

CASE 4.—A boy aged 6 years was struck by an automobile on Jan. 22, 1933. Examination on his admission to the hospital showed a laceration of the scalp, cervical rigidity and a questionable positive Babinski sign on the left side.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
1/23/33	Semistuporous	400	32	1% blood
1/24/33	Still semistuporous; tossed about	300	30	0.3% blood
1/25/33	Comatose	300	28	Trace of blood
1/26/33	A little better	360	35	Trace of blood
1/27/33		300	44	Trace of blood
1/28/33	A little brighter	260	23	Slightly bloody
1/30/33	More rational; less stuporous	230	18	Clear
1/31/33	Restless	260	25	Clear
2/ 1/33	Improving	160	15	Clear
2/ 4/33	"Fogged," but no headache and no complaints	200	22	Clear
3/ 7/33	Symptom-free			
6/ 6/33	Well; going to school			

The patient's improvement was progressive and uneventful, particularly when the pressure was reduced to 230 mm. Restlessness recurred when the pressure was 260 mm.; improvement occurred again when the pressure was 160 mm.

CASE 5.—A man aged 28 was injured in an automobile collision on May 8, 1932. He was unconscious for several hours. Examination showed a laceration of the

scalp, distention of the bladder and a slow pupillary reaction. A fracture of the right side of the front of the skull extended into the orbit.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
5/ 9/32	Comatose	300	23	Moderately bloody
5/10/32	Vomited	300	16	Moderately bloody
5/11/32		250	25	Blood tinged
5/12/32	Incontinent	125	12	Slightly bloody
5/18/32	Very rational	140	15	Faintly yellow
5/22/32	Fully conscious			

Stupor persisted for five days. With a progressive fall in the pressure, there was return of consciousness when the pressure was reduced to normal.

Case 6.—A man aged 32 was struck by a street car on Feb. 22, 1933. Examination on his admission to the hospital showed stupor, a laceration of the scalp, cervical pain and rigidity. The right eyelids were ecchymotic, and blood was present in the left aural canal. The Babinski and Chaddock signs were positive bilaterally. Fractures were present in the left parietal region and in the second cervical vertebra.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
2/22/33		410	35	50% blood
2/22/33	Stuporous	300	30	0.01% blood
2/23/33	Irrational	250	25	Slightly red
2/24/33	Rational	275	25	Slightly red
2/25/33	Better	325	35	Bloody
2/26/33		250	5	Slightly bloody
2/27/33		270	25	Slightly yellow
2/28/33	Restless and noisy; temp. 103 F.; otitis media and mastoiditis	400	40	Clear
3/ 1/33	Improved: drowsy	270	40	Slightly yellow
3/ 2/33	Less restless	110	5	Light yellow
3/ 4/33		150	25	Light yellow
3/ 5/33	Rational			

The patient was stuporous and irrational, with a high spinal fluid pressure (410 mm.), until after the fourth puncture, when he became rational. He again became irrational and had a high pressure, when mastoiditis developed, and finally he became rational after the spinal fluid pressure was reduced to normal.

Subgroup 2: Drainage Delayed From Five to Eight Days.—There were nine patients in whom, although there was a progressive fall in pressure with corresponding clinical improvement, the treatment for some reason was delayed until after the fourth to the seventh day.

The outstanding feature in these patients was the persistence of pressure symptoms before drainage and the marked and almost spectacular immediate (subjective) improvement in symptoms after the first puncture. The only apparent difference in the pressure in this group as compared with that in the group of patients who were treated early was that in the latter the average pressure of the last puncture was 20 mm. lower. The severity and persistence of the symptoms in patients in whom drainage was delayed has convinced me that in most instances treatment is indicated as soon as the patient comes under observation.

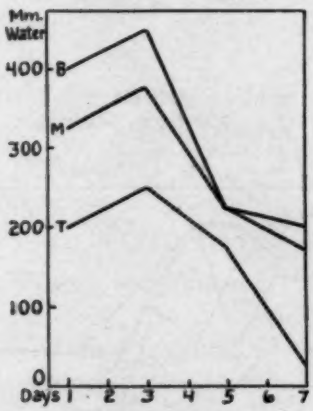

Chart 3.—Curves (designated by the initial of the patient) showing the progressive fall in the spinal fluid pressure of patients on whom drainage was done within the first or second day after injury. *B* indicates the curve for the patient in case 1, and *M*, the curve for the patient in case 3.

The following cases (chart 4) illustrate this group:

CASE 7.—A man aged 27 was struck by an automobile on May 3, 1932. Coma lasted for thirty minutes. Examination showed laceration of the scalp, cervical rigidity and fracture of the skull in the left temporal bone.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
5/ 7/32	Severe headache			
5/ 8/32	Severe pain in the head	300	30	Very bloody
5/ 9/32	Improved but still much headache	300	25	Moderately bloody
5/11/32		200	15	Clear
5/13/32	No headache	200	?	Slightly yellow

Treatment was delayed for five days; thereafter an elevated spinal fluid pressure persisted. However, clinical improvement resulted after repeated drainage.

Case 8.—A boy aged 12 years fell from a car on Feb. 24, 1933, and was in coma for twenty-four hours. Severe headache followed. Examination showed ecchymosis of the left eye, bilaterally positive Babinski and Chaddock signs and a fracture in the left temporal bone extending into the middle cranial fossa.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
3/ 2/33	Severe headache	340	36	Clear
3/ 3/33	"Much better since spinal puncture yesterday"	335	50	Clear
3/ 4/33	"Perfectly well now"	250	45	Slightly yellow
3/ 5/33	Very well; wanted to go home	400	50	Clear
3/ 6/33		310	25	Slightly yellow
3/ 7/33		215	40	Slightly yellow
3/ 9/33	Very well; wanted to go home	175	20	Slightly yellow
3/10/33	Very well; wanted to go home	215	25	Slightly yellow

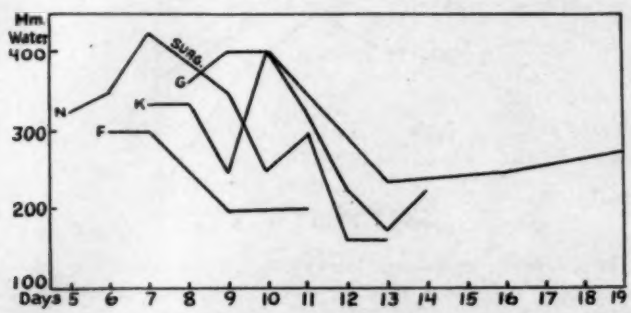

Chart 4.—Curves (designated by the initial of the patient) showing the progressive fall in the spinal fluid pressure of patients on whom drainage was delayed for five, six, seven and eight days. *F* indicates the curve for the patient in case 7; *K*, the curve for the patient in case 8, and *G*, the curve for the patient in case 9.

There were severe concussion with pathologic reflexes and fracture of the skull, severe headache and high pressure (340 mm.). Treatment was delayed for six days; symptoms were relieved immediately by drainage; however, the pressure remained high until after the fifth puncture.

This case illustrates the difficulty in reducing pressure when treatment is delayed. Relief from symptoms was obtained on drainage.

Case 9.—A Mexican aged 25 was struck on the head on Jan. 10, 1933; the duration of coma was unknown. He was admitted to the hospital seven days later, complaining of severe headache. Examination revealed cervical rigidity, papilledema of 3 diopters, retention of urine and an Oppenheim reflex on the right.

A vertical occipital fracture was present. The headache immediately improved after the first spinal drainage.

Date	State of Patient	Initial Presence, Mm.	Fluid Removed, Cc.	Appearance
1/17/33	Pulse rate, 54 to 60	360	45	Slightly bloody
1/18/33	Better; pulse rate, 52 to 60;	400	40	Slightly bloody
	still some headache	400	50	Slightly bloody
1/21/33	Less headache but still groaned; pulse rate, 68 to 100	230	38	Trace of blood
1/24/33	Slept considerably	250	8	?
1/27/33	Ambulatory; slight headache	270	35	Clear
1/30/33	"Felt fine"			
1/31/33	Discharged			

There were concussion and fracture of the skull, high pressure and severe headache. Treatment was delayed for seven days; marked improvement occurred when the pressure reached 230 mm. It was difficult to get the pressure below 230 mm. (delayed treatment).

GROUP B: SUSTAINED PRESSURE

There were twelve patients in whom the pressure of the cerebrospinal fluid continued high (from 200 to 400 mm.) in spite of repeated spinal drainage. In some of these patients there was an abrupt drop to around 200 mm., but subsequent punctures again showed a high pressure. In general, pressure symptoms continued and did not improve until after several punctures had been done. In a few patients the headache disappeared early in the series of drainages, although the pressure continued at a high level. In every patient the headache was finally controlled if treatment was continued faithfully.

I can offer no satisfactory explanation for the sustained pressure in this group other than the possibility that there were actually more concussion and stimulation to the choroid plexuses, resulting in a greater output of cerebrospinal fluid with possibly loculated subdural fluid. Most patients presented a clinical picture which paralleled the high pressure, for in the group there were two deaths, and it was necessary to operate on four patients. This clinical correlation was not constant, however, for headache disappeared readily in two patients who continued to have elevated pressure (from 250 to 300 mm.).

This group of patients was subdivided into those whose treatment was instituted early and those whose treatment was delayed. Here again there was no difference clinically other than a failure of the symptoms to improve until spinal drainage was instituted.

The following cases are representative of the group.

Case 10.—A man aged 31 was injured in an automobile accident on Jan. 28, 1933. He was in coma for one hour and stuporous thereafter. Examination revealed laceration of the scalp, cervical rigidity, absence of the right abdominal reflex and positive Babinski, Chaddock and Oppenheim signs bilaterally.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance.
1/30/33	Stupor; headache	200	25	1% blood
1/31/33	Stupor; pulse rate, 52	220	23	Slightly bloody
2/ 1/33	Conscious; some headache; pulse rate, 45	300	34	Yellow
2/ 2/33	Less headache; ate; pulse rate, 56	300	35	Yellow
2/ 3/33	Same, but less headache; pulse rate, 56	230	32	Slightly bloody
2/ 4/33	Headache continued; pulse rate, 72	300	28	Slightly bloody
2/ 5/33	Headache continued; pulse rate, 70	250	34	Slightly bloody
2/ 6/33	No headache; pulse rate, 76			
2/ 7/33	Up; felt well; pulse rate, 68	250	40	Clear
2/ 8/33	No complaints; pulse rate, 62	270	40	Clear
2/ 9/33	No complaints	250	42	Clear
2/10/33	Felt "like a million"	200	34	Clear
2/11/33	No complaints	210	34	Clear

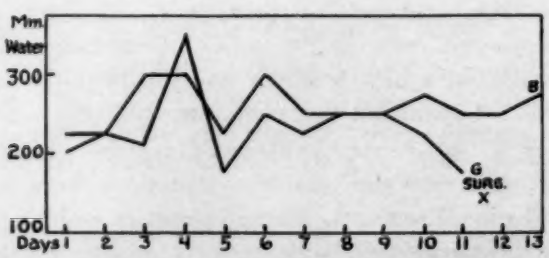

Chart 5.—Curves (designated by the initial of the patient) showing the sustained high spinal fluid pressure in spite of repeated drainage. *B* indicates the curve for the patient in case 10. In this case the pressure was still elevated after the thirteenth puncture. Patient G died after surgical intervention (indicated by *x*).

Increased spinal pressure was sustained (from 200 to 300 mm.), but pressure symptoms definitely improved after the pressure was kept below 250 mm.

Case 11.—A sailor aged 19 was thrown from a motorcycle on Sept. 18, 1931. He was admitted to the hospital in deep coma with stertorous respiration. Examination revealed laceration of the scalp, epistaxis and ecchymosis of each eye.

The neck was rigid anteroposteriorly, and the Babinski sign was positive bilaterally. The pulse rate was 68 and the temperature varied from 100 to 102 F. No fracture was shown roentgenographically.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
9/19/31				
10 a. m.	Still in deep coma	400	45	Slightly bloody
9 p. m.		400	45	Slightly bloody
9/20/31				
10 a. m.	In deeper coma; temp., 103 F.	200	25	Slightly bloody
7 p. m.	Right hemiparesis	350	30	Slightly bloody
9/21/31	Operation: left subtemporal decompression; a large amount of subdural clot and blood-tinged fluid, with severe cortical contusion, subpial hemorrhage and increased intracerebral tension; drainage of subdural space	300	35	More bloody
9/22/31	Coma lighter; temp., 101.6 F.			
9/23/31	More restless; pulse rate, 70	280	25	Yellowish
9/24/31	Much improved; less stuporous			
9/26/31	Some improvement	380	45	Slightly bloody
9/28/31	Improved	400	70	Clear
9/29/31		380	45	Clear
10/ 2/31	Took fluid well	140	30	Clear
10/ 8/31		150	16	Clear
10/13/31	Conscious; motor aphasia	200	24	Clear

The patient suffered from severe concussion, cortical contusion and a basilar fracture. There were a high cerebrospinal fluid pressure and an excessive amount of spinal fluid with a localized subdural clot. The patient became worse on the third day despite drainage of the spinal fluid, the pressure remaining high. There was improvement after the surgical removal of the clot and drainage, but the pressure still remained high (from 280 to 400 mm.); the patient was stuporous for nine more days until the pressure became lower (from 140 to 150 mm.). He was conscious on the twenty-fifth day, when the pressure was found to be only 200 mm.

This is a case in which spinal drainage was insufficient, and continued failure indicated a surgical lesion. In addition, postoperative drainage of the spinal fluid was also indicated.

CASE 12.—A man aged 32 was in an automobile accident on Feb. 1, 1933. He was rendered unconscious, had convulsions and vomited once. Examination revealed cervical rigidity, ecchymosis of the left eye, laceration of the scalp, a

positive Babinski sign bilaterally and pathologically positive deep reflexes. No fracture was shown roentgenographically.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance.
2/ 1/33	Deep coma	200	20	11% blood
2/ 2/33	Semicomatose	250	26	4% blood
2/ 3/33	Could be aroused	300	32	Trace of blood
2/ 4/33	Talked loudly	320	32	Yellow
2/ 5/33	Condition the same	210	28	Slightly yellow
2/ 6/33	More rational	190	24	Clear
2/ 7/33	Quiet; no restraints	210	?	Clear
2/ 9/33	Entirely rational	250	?	Clear
2/11/33	Awake; remembered nothing since accident	190	?	Clear

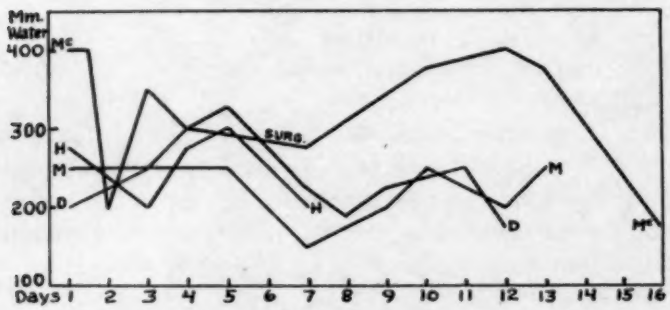

Chart 6.—Curves (designated by the initial of the patient) showing the sustained high spinal fluid pressure in spite of repeated drainage. *Mc* indicates the curve for the patient in case 11, and *D* the curve for the patient in case 12. In case 11 the pressure was still elevated until after the fourth postoperative puncture.

The patient was comatose and irrational for eight days. The spinal fluid pressure ranged from 200 to 320 mm. He became markedly better when the pressure reached 190, and did not relapse, even though the pressure rose again to 250 mm.

GROUP C: SECONDARY RISE AFTER "NO DRAINAGE INTERVAL"

The third group of patients, a most interesting one, presented a secondary rise in pressure (from 200 to 400 mm.) after an interval without treatment. This group best illustrates the necessity of continued observation and drainage at close intervals in order to keep cerebrospinal fluid pressure normal. There was not always a return of headache and stupor when the pressure would be found elevated after an interval of no drainage, but whenever symptoms did return, the pressure was always found high, and symptoms were relieved by drainage.

The period of no drainage varied from two to several days. It was found that an interval early in the course of treatment was more likely to result in a secondary rise of pressure than was a similar interval later in the course of observation. This should emphasize the necessity of an early and earnest attempt at reestablishing normal cerebrospinal fluid pressure.

The group was divided into (1) those patients whose pressure had been reduced from high (from 300 to 400 mm.) to nearly normal,

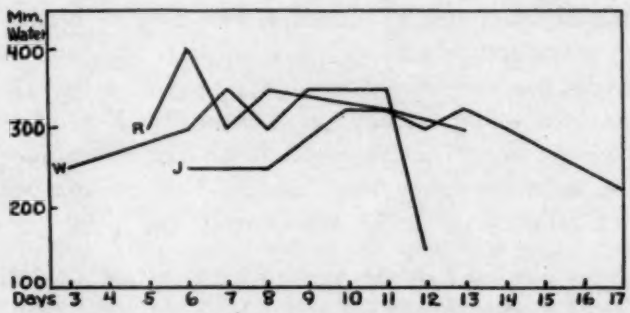

Chart 7.—Curves (designated by the initial of the patient) showing the sustained high spinal fluid pressure in spite of repeated drainage.

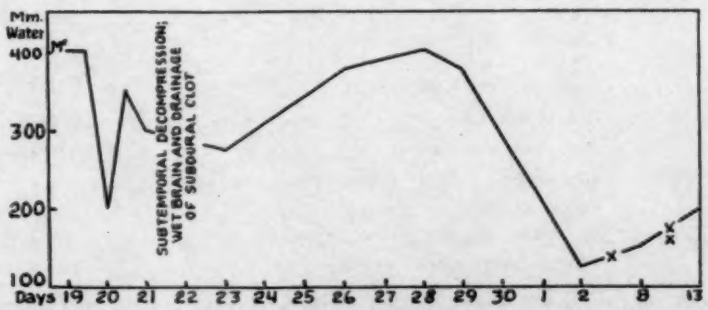

Chart 8.—Spinal fluid pressure curve for the patient in case 11. The pressure was sustained after operation until after the fourth puncture. The *x* indicates an interval of six days and *xx*, an interval of five days.

then after a "no drainage interval" was found to be high (charts 9 and 10) and (2) those whose pressure was at first nearly normal, but later after a "no drainage interval" secondarily rose to from 250 to 300 mm. (chart 11). For instance, a patient was injured on April 3, 1932. The pressure that day was 175 mm. No puncture was done again until April 6, when the pressure was 325 mm.; on

April 8 it was 325 mm. and on April 11, 350 mm. In the presence of continued stupor and headache after the first spinal puncture, drainage should have been repeated at least every twenty-four hours to insure against such secondary rise.

The cases reported here illustrate that observation should extend from two to three weeks in the presence of concussion in order to discover a secondary recurrence in symptoms and a rise in pressure.

Caution must be observed, however, in interpreting these recurrences, for instead of a simple reaccumulation of cerebrospinal fluid which could easily be controlled by drainage, one may be dealing with an (interval) extradural hematoma or a subacute subdural hematoma, in which case not only would surgical intervention be indicated but spinal punctures would actually be contraindicated. Only experience in close observation of clinical symptoms and interpretation of neurologic signs can differentiate these lesions. This question will be discussed later. However, case 13 will illustrate this point.

Case 13.—A man aged 44 was drunk and fell on Nov. 23, 1931. On his admission to the hospital he was stuporous. A fracture was present in the left parietal region.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
11/23/31		280	?	Blood tinged
11/24/31		150	8	Clear
11/27/31	Aphasic; restless	400	30	Clear
11/28/31	More stuporous	400	35	Clear
	Left hemiparesis	300	30	Clear
11/29/31	Operation: right subtemporal decompression; subdural and intracerebral hemorrhage; death twelve hours after operation			

In this case there was a delayed but marked increase in both generalized pressure and localizing signs which did not improve readily under drainage; these indicated a surgical lesion. Surgical intervention was delayed too long. Failure of the patient to improve within the first twelve hours after such a rise in pressure should indicate operation.

Another patient was injured on Sept. 29, 1932. Pressure on the second day was 125 mm.; on the sixth day, 450 mm.; on the seventh day, 450 mm.; on the eighth day, 350 mm., and finally, on the ninth day, 175 mm.

Subgroup 1: First Pressure High.—Case 14.—A man aged 23 was thrown about 50 feet from a motorcycle on March 1, 1933. Examination on his admis-

sion to the hospital showed him to be in a confused mental state, with laceration of the scalp and cervical rigidity. A left parietal fracture was demonstrated roentgenographically.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
3/ 1/33	Confused	490	15	10% blood
3/ 2/33	Severe headache and pain	100	3	0.2% blood
3/ 4/33	Relieved by spinal puncture	250	10	Bloody
3/ 4/33	Relieved by spinal puncture	400	20	Blood tinged
3/ 5/33	Patient stated that relief of headache after spinal puncture was immediate and lasted from 6 to 8 hours; complained of severe headache in morning and could not raise head from pillow			
3/ 5/33		400	20	Clear; yellow
3/ 6/33	Headache only slight	50	0	Clear; colorless

The first spinal fluid pressure was high; the second was low. No drainage was done on third day; on fourth and fifth days the pressures were again elevated.

Case 15.—A man aged 27 fell from his horse on May 24, 1931. The neck was rigid; the Babinski sign was positive on the right.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
5/25/31	Arousing; headache	300	40	Bloody
5/26/31	Irrational	130	15	Bloody
5/28/31	More rational	300	30	Blood tinged
5/29/31	Very stuporous			
5/31/31	Operation: right subtemporal decompression; large amount of clear yellow cerebrospinal fluid subdurally under pressure			

A secondary rise in pressure from 130 to 300 mm. occurred after an interval of one day. A large amount of fluid was found subdurally at operation.

Case 16.—A boy aged 16 years was struck by an automobile on August 5, 1932, causing stupor, emesis and fracture in the left parietal region.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
8/ 7/32	Stuporous	300	35	Bloody
8/ 8/32	Less stuporous	220	30	Clear
8/ 9/32		160	35	Bloody
8/14/32		300	25	Clear

There was a progressive fall of pressure from 300 to 160 mm. and then a secondary rise to 300 mm. after a "no drainage interval" of five days.

Case 17.—A man aged 29 was in an automobile accident on May 8, 1932. Examination showed him to be in profound coma and involuntary, with a temperature of 104.6 F. There were abrasions of the face and scalp, ecchymosis of the left eye and small fixed pupils. The right clavicle and humerus were fractured.

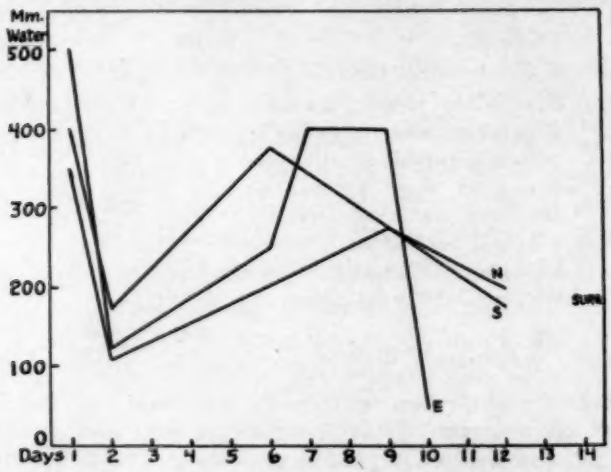

Chart 9.—Curves (designated by the initial of the patient) showing a secondary rise in spinal fluid pressure after a "no drainage interval" of from four to seven days. The first pressures were high. *E* indicates the curve for the patient in case 14.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
5/10/32	Slightly improved	350	25	Moderately bloody
5/11/32	Coma	350	25	Moderately bloody
5/12/32	Coma	375	35	Blood tinged
5/13/32	Coma	275	15	Clear; colorless
5/14/32	Temp., 105 F.; bronchopneumonia	125	5	Clear; colorless
5/18/32	Coma			
5/21/32	Coma; improved			
5/26/32	Left pupil larger; Babinski sign bilaterally			
5/27/32	More conscious; aphasia	325	30	Clear; colorless
6 /4/32	More conscious	280	20	Clear; colorless
6/ 8/32		180	15	Clear; colorless
6/20/32	Operation: left subtemporal decompression; brain contused and very wet; large amount of drainage for two days			
6/22/32	Looked better			
7/13/32	Asked for water			
7/26/32	Fed self	200	15	Clear; colorless

The patient suffered from concussion and contusion. The pressure was high but came down to 125 mm. on the fifth puncture. A later series of punctures brought the pressure from 325 to 180 mm. An operation, draining the subdural space of much fluid, gave definite improvement. Spinal puncture thirty-six days later gave a pressure of 200 mm. The patient asked for water on the sixty-third (posttraumatic) day. His mental state improved on the eightieth day. He was discharged on the ninetieth day, with a drawling speech, impairment of hearing and a Babinski sign on the right. Two months later he could walk, but with a spastic gait.

This patient was adequately treated by spinal drainage, but surgical drainage was necessary to drain the subdural space. This might better have been done earlier.

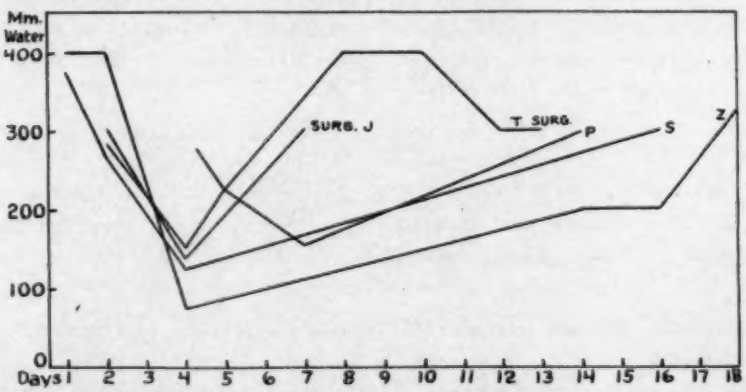

Chart 10.—Curves (designated by the initial of the patient) showing a secondary rise in spinal fluid pressure after a "no drainage interval" of from one to seven days. The first pressures were high. *J* indicates the curve for the patient in case 15; *T*, the curve for the patient in case 13; *P*, the curve for the patient in case 16, and *S*, the curve for the patient in case 17.

Subgroup 2: First Pressure Low.—Case 18.—A man aged 46 was struck by an automobile on April 3, 1932. Examination on his admission to the hospital showed him to be irrational. The pupils were unequal, and the neck was rigid. The skull was fractured in the right temporal and left occipital regions.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
4/ 3/32	Semicomatose	175	15	Very bloody
4/ 6/32	Still drowsy	325	15	Moderately bloody
4/ 8/32		325	18	Bloody
4/11/32		350	20	Blood tinged

The spinal fluid pressure at first was relatively low (175 mm.), but was found to be elevated (325 mm.) after a "no drainage interval" of two days.

CASE 19.—A man aged 39 was struck on the head with a chair on May 14, 1932. He was dazed, but not unconscious. Examination revealed laceration of the scalp, cervical rigidity and a fracture of the skull in the left parietal area. He complained of severe headache.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
5/18/32	Severe headache	150	5	"Almost pure blood"
5/20/32	Severe headache	350	30	Very bloody
5/23/32	Severe headache	218	30	Clear; yellow
5/24/32	Headache better			
5/25/32		175	15	Slightly yellow

The first pressure was normal, but two days later it was elevated to 350 mm.

CASE 20.—A Mexican aged 32 was unconscious for thirty minutes after an automobile accident on April 24, 1932. Examination showed cervical rigidity, bleeding from the right ear, ecchymosis of the left eye and a double linear fracture of the skull in the right occiput.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
4/27/32	Headache and vomiting	175	8	Moderately bloody
5/ 2/32	Temp., 103 F.; mastoiditis	300	20	Clear
5/ 4/32	Temp., 105 F.; mastoidectomy	300	16	?

After a "no drainage interval" of five days the pressure had increased from 175 to 300 mm.

CASE 21.—A Mexican youth aged 18 was in an automobile accident on Sept. 29, 1932, and sustained injuries of the back and head. Examination showed cervical rigidity and tenderness, paresis of the right arm and leg and a positive Babinski sign bilaterally. A fracture was present in the right parietal area.

Date	State of Patient	Initial Pressure, Mm.	Fluid Removed, Cc.	Appearance
9/30/32	Coma	125	3	Bloody
10/ 4/32	Coma	450	16	Bloody
10/ 5/32	Coma	450	12	Blood tinged
10/ 6/32	More conscious	350	11	Yellow
10/ 7/32	More conscious	175	8	Yellow
10/ 8/32		15	0	
10/14/32	More rational			

The spinal fluid pressure increased from 125 to 450 mm. after a "no drainage interval" of four days, returning to normal on repeated drainage.

SURGICAL DRAINAGE

The question of surgical intervention in cases of head injury is an important and difficult one. A large experience in clinical observation

and interpretation of the clinical course and neurologic signs is indispensable in determining the time and type of intervention. It goes without saying that a knowledge of the physiologic and pathologic pictures of intracranial pressure is most essential.

This series of patients afforded an excellent opportunity to study the preoperative and the postoperative clinical course as compared with the spinal fluid pressure findings and to check both of these with surgical and postmortem observations.

INDICATIONS

The indications for surgical intervention depend entirely on a diagnosis. All that one can expect to accomplish by surgical measures is to remove or drain a lesion which is causing pressure. Of these lesions,

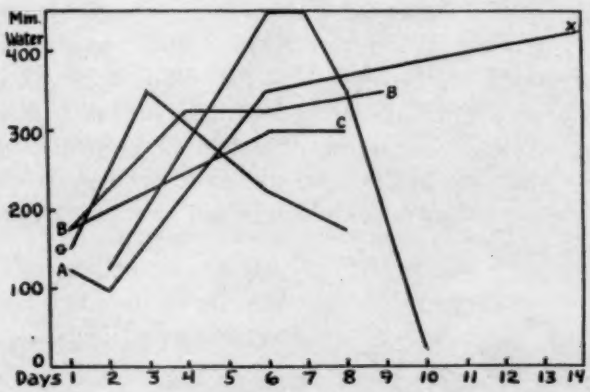

Chart 11.—Curves (designated by the initial of the patient) showing a secondary rise in spinal fluid pressure after a "no drainage interval" of from one to three days. The first pressures were low. *B* indicates the curve for the patient in case 18; *G*, the curve for the patient in case 19, and *C*, the curve for the patient in case 20. *X* indicates the finding of choked disks. Operation performed fifty-four days later showed excessive subdural and subarachnoid fluid.

there are only three: (1) extradural hematoma, (2) subdural hematoma and (3) a subdural (extra-arachnoid) accumulation of fluid.

The third lesion is by far the most commonly neglected one. It consists of cerebrospinal fluid which is loculated subdurally, either by seepage through the arachnoid due to increased subarachnoid pressure or to arachnoidal tears. This lesion was present in ten of the fourteen cases in this series in which operation was performed. It is immediately recognized as a "gush" of yellow or pink fluid when the dura is opened. It is easily removed by a trephine sufficiently large to admit a surge-

line drain. The drainage is profuse for from twelve to thirty-six hours, after which it usually ceases.

Subdural accumulation of fluid is by far the most common operative lesion and no doubt the least recognized. Differentiation from a subdural hematoma is not easy. Its presence may well be suspected when, after the third or fourth day, in spite of repeated spinal drainage, stupor, coma and headache fail to improve. In addition, a most valuable and almost unfailing accompanying finding is the persistence of high cerebrospinal fluid pressure (charts 5, 6 and 7).

The presence of cortical contusions may materially distort the picture and cause considerable difficulty in diagnosis. To the inexperienced surgeon, hemiparesis resulting from contusions may tend to urge him to explore. The outstanding feature of contusion causing paresis and reflex changes is the presence of these findings almost immediately after injury, particularly if associated with clear or improving consciousness. There may or may not be high cerebrospinal fluid pressure. Such localizing findings which had been present from the first in a patient who is slowly, over a period of days, becoming more stuporous, suggests contusions plus subdural hematoma or subdural accumulation of fluid. Even when complicated by either of the latter two lesions, the presence of paresis from the moment of injury is still indicative of cortical contusion or laceration.

LESIONS FOUND AT OPERATION

Before discussing the clinical aspect of cases in which operation was performed, it will be of value to give an idea of the surgical lesions actually found at operation in fourteen cases.

The most common lesion was the typical "wet brain" caused by subdural and subarachnoid collections of fluid. This was present in ten cases. Extradural hematoma was found once, subdural hematoma three times, intracerebral hemorrhage once and finally only a red, swollen brain twice. One of these was very dry; the other had some fluid, but the exact description was not recorded. The brief case reports which follow will give the type of lesion and the corresponding picture produced by spinal fluid pressure.

CLINICAL COURSE

Course.—In general, all patients became worse preoperatively and improved postoperatively. There were two deaths immediately after operation, one from intracerebral hemorrhage and one from cardiorenal and coronary disease. The third death occurred fifteen days post-

operatively from pneumonia. The state of the patient before operation and the result afterward are recorded in the following tabulation:

Symptom Before Operation	No. of Cases	Results After Operation	No. of Cases
Headache	4	Improvement	4
Coma	10	Revival	7
Hemiparesis	10	Improvement	8
Choked disks	2	Recession	2
Aphasia	5	Improvement	4
Spinal pressure sustained or increasing	12	Sustained or declined	8
Reflex changes	12	No record	
Pupillary inequality	6	No record	

All patients had a high spinal fluid pressure at some time before operation, and nine had a pressure over 250 mm. immediately before operation (charts 12 to 15).

There were three exceptions. The patient in case 22, after two punctures, had a preoperative pressure of 175 mm. At operation the brain showed considerable pressure and fluid subdurally. At postmortem examination (death fifteen days after operation due to pneumonia) there was no gross cerebral lesion, showing that spinal puncture and operation had removed the fluid by drainage. The other patient had had ten spinal punctures preoperatively, the last pressure being only 175 mm.; only a dry red brain was found at operation. Postmortem examination showed diffuse basilar subdural clots with laceration of the left temporal lobe, but no evidence of pressure on the brain! The patient in case 23 had a preoperative pressure of 175 mm., four spinal punctures having been done. There were redness and laceration of the cortex and considerable subdural clot, but no excess fluid.

The preoperative pressure of these three patients was relatively low (175 mm.). The first patient had only two spinal punctures, and much fluid remained. The second and third patients had ten and four spinal punctures, and the brains at autopsy (although having some subdural clots) showed little excess fluid and little evidence of cerebral compression.

There was often a tendency to be hurried into operation by the presence of hemiparesis, aphasia or both, even when the patient's consciousness and other signs of pressure showed improvement. The patient in case 23 was conscious and rational and had a normal spinal fluid pressure. There may have been some question regarding the necessity of removing a small amount of subdural clot to prevent later convulsions, but the course was favorable, and as there were no signs of pressure, surgical intervention was not indicated. Signs of deepening coma and increasing spinal pressure should cause much more concern than localizing signs. The latter are usually caused by contusions and

lacerations (not operable), while the former result from excess fluid or clots. In order for surgical measures to accomplish anything, there must be removal or drainage to provide more space. Since contusions and lacerations require little more space than normal brain, a definite differential diagnosis is necessary when considering operation.

Pupillary inequality should attract considerable attention in making a diagnosis of a surgical lesion, for in the comatose patient this sign is often the earliest and the most reliable sign localizing a pressure-producing lesion. Almost invariably one will find that when the patient is still conscious or lightly stuporous (stage of cerebral irritation) the pupil will be smaller on the side of the lesion. However, and this is more important, when the patient is moderately or deeply comatose, the lesion will be found on the side of the larger pupil. This sign was present in six cases and in every case indicated the side of the lesion. I have seen this sign fail but once, and that time it was thought that the patient had an additional lesion of the third nerve on the side opposite the hemorrhage.

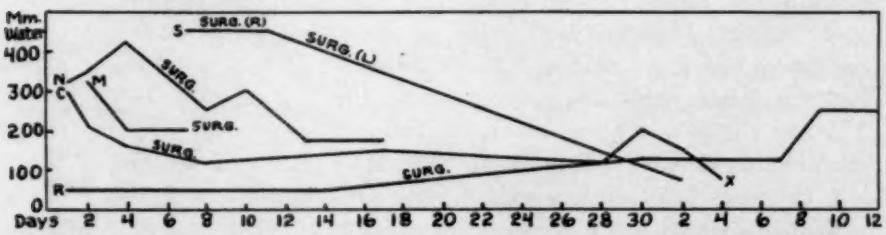

Chart 12.—Curves (designated by the initial of the patient) showing lowered spinal fluid pressure after surgical drainage. *S* indicates the curve for the patient in case 24; *M*, the curve for the patient in case 26; *C*, the curve for the patient in case 22, and *R*, the curve for the patient in case 29. All the patients recovered with the exception of one, who died of pneumonia (indicated by *x*).

Case 13.—A man, aged 44, suffering from syphilis and addicted to the use of alcohol, sustained concussion and coma. On the sixth day spastic paresis developed on the left side, and the coma deepened. The spinal pressures were 280, 150, 400 and 300 mm. Signs of early medullary failure and hyperthermia developed. Operation showed subdural and intracerebral hemorrhage. Death occurred. In this case the spinal pressures paralleled the degree of coma and the localizing signs.

Case 23.—The patient was in coma for four days after an injury and then awakened but was aphasic. Spinal punctures showed pressures of 400, 175, 375 and 175 mm. Operation revealed the dura to be tight and blue and the cortex lacerated and red, with some subdural hematoma. The patient was doing well before the operation. The spinal pressure had returned to normal or at least was being controlled by spinal drainage. Operation did not accomplish anything. The aphasia should not have been an indication for intervention.

CASE 24.—The patient was admitted to the hospital after five days of headache resulting from a blow on the head. The spinal pressure was 450 mm. Subtemporal decompression showed a swollen, red, contused cortex. No record was made of the amount of fluid, but a drain was inserted. Spinal pressure the next day was again 450 mm., so on the second day subtemporal decompression was done on the opposite side. Again no record was made of the findings, but the wound was drained, and the patient was remarkably improved and free from symptoms four days after the second operation. The patient's treatment was delayed for five days, but it is my opinion that he would have recovered as well by repeated spinal drainage.

CASE 25.—In this patient the preoperative spinal fluid pressure was 175 mm. Surgical exploration revealed a red, dry cortex not under increased tension. There was no excessive amount of fluid. The relatively low spinal fluid pressure should have indicated that there was little probability of an operable lesion.

There was one case in which an extradural hematoma was present and four cases in which there were subdural collections of fluid, which

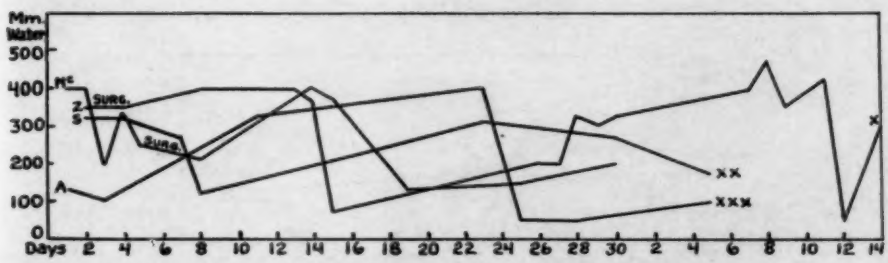

Chart 13.—Curves (designated by the intial of the patient) showing variations in the spinal fluid pressure (in two cases before operation and in two cases afterward). Often a much lower pressure was found the day after drainage. *Mc* indicates the curve for the patient in case 11; *S*, the curve for the patient in case 17; *A*, the curve for the patient in case 28, and *Z*, the curve for the patient in case 31. Patient *Z* woke fourteen days after the time indicated by *x*; patient *A* had a pressure of 400 mm. forty-four days after the time designated by *xxx*, and operation was performed seventy-eight days later; patient *S* was operated on twelve days after the time designated by *xx*, and the spinal fluid pressure was 200 mm. forty-eight days later.

will be described later under postoperative spinal drainage. Four additional cases in which there was excessive subdural fluid will be presented to emphasize the preoperative clinical course and the spinal fluid pressure.

CASE 26.—The patient's coma became deeper on the third day, and paresis developed on the left side. Spinal punctures showed pressures of 315, 200 and 200 mm., but the patient did not arouse after drainage. Operation performed on the fourth day revealed an excessive amount of fluid subdurally and a swollen cortex. There was much drainage postoperatively. The patient began to arouse on the sixth postoperative day, became rational on the ninth day and began to move the left side on the twentieth day; therefore no postoperative spinal drainage

was done. The sustained spinal fluid pressure and deepening coma with hemiparesis indicated operation for the drainage of subdural fluid which could not be adequately drained by the spinal route.

CASE 15.—The patient became more stuporous on the sixth day after injury, with a slow pulse, weakness of the left side of the face and spinal pressures of 300, 130 and 300 mm. Operation revealed a large amount of clear yellow fluid subdurally which continued to ooze through the arachnoid. The patient became more rational on the eleventh day but was not conscious until the eighteenth day. Three months later he stated that he was physically perfect and without headache but had deafness and tinnitus in the left ear. He also had a "wet brain" which could not be successfully managed by spinal drainage; however, postoperative drainages would probably have hastened the recovery of consciousness.

CASE 27.—The patient was in coma for four hours and was doing well except for increasingly severe headache, weakness on the right side and a larger pupil on the right than on the left. Spinal fluid pressures of 195, 180, 450, 230 and 240 mm. were obtained. Operation revealed a greenish blue dura, with a moderate amount of blood-tinged fluid beneath. The cortex was badly contused. Spinal fluid pressure on the third postoperative day was 280 mm. The drainage of 18 cc. of fluid relieved all symptoms, and the patient was still free from symptoms the next day.

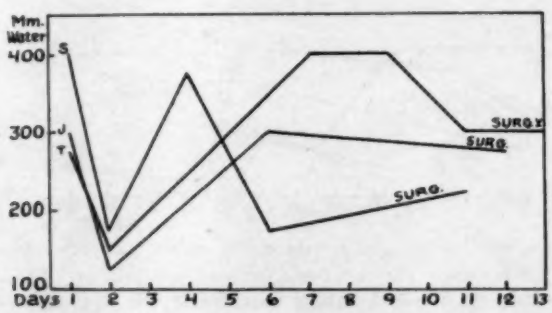

Chart 14.—Curves (designated by the initial of the patient) showing a low spinal fluid pressure the day after drainage, then a secondary rise followed by surgical drainage. *S* indicates the curve for the patient in case 23; *J*, the curve for the patient in case 15 and *T*, the curve for the patient in case 13. Death occurred in case 13 (indicated by *x*) due to intracerebral hemorrhage.

CASE 28.—This was a most interesting case. The patient was in coma for seventeen days with paresis on the right side, followed by aphasia. Later he contracted pneumonia, then otitis media and pain in the region of the mastoid. His speech returned by the twenty-eighth day. Spinal pressures of 130, 100, 350 and 400 mm. were obtained; then after drainage of from 10 to 30 cc. at a time the pressures were 50, 50 and 100 mm. There was no headache and no other complaints when on the seventy-first day, during an examination preceding discharge, choked disks were found and the spinal pressure was discovered to be 400 mm. Choked disks were still present two months later, whereupon a subtemporal decompression was done on the left side, revealing a tremendous amount of subdural yellow fluid. The brain receded from the skull after drainage of the fluid. Eight months later the disks appeared to be practically normal, and the boy was working hard without symptoms.

This case illustrates most forcibly the fact that some patients, particularly children, do not suffer from headache when they have increased intracranial pressure, even though the pressure is high enough to measure 400 mm. on the manometer and produce choked disks of 5 diopters, and that if there is the least indication of increased pressure after head injury, a puncture should be done to check the pressure and drain the excess fluid.

Case 17.—The patient was in profound coma with a temperature of 104 F. immediately after injury. Pressures of 350, 350, 375, 275 and 125 mm. were obtained on successive days. Another series of punctures, begun fourteen days later and about four days apart, showed pressures of 325, 280 and 180 mm. The patient was still in coma after forty-three days; the left pupil was larger than the right, and the disks were blurred. Decompression in the left subtemporal region showed cortical contusion and an excessive amount of fluid; there was copious drainage of fluid for one or two days. On the sixty-third day the patient could ask for water and looked more intelligent. By the eightieth day there had been a

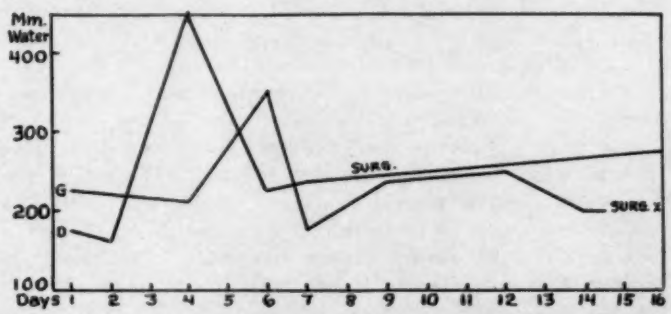

Chart 15.—Curves (designated by the initial of the patient) showing the spinal fluid pressure in cases in which surgical drainage was done. *G* indicates the curve for the patient in case 25, in which death occurred (*x*), due to cardiorenal disease; and *D*, the curve for the patient in case 27.

remarkable improvement in his mental status. On his discharge on the ninetieth day he had a drawling speech and some impairment of hearing. Two months later he had a spastic gait and slurring speech.

Postoperative Course.—There were three postoperative deaths, one from intracerebral hemorrhage, one from coronary disease and one from pneumonia.

All patients (four) conscious enough to complain of headache before operation were relieved of the headache postoperatively. Consciousness, however, was not quick to return; patients revived on the ninth, ninth, eleventh, twelfth, sixteenth, thirty-sixth and fifty-second day after operation. The patient usually regained consciousness slowly, although one patient (case 31) remained in coma for fifty-two days, then suddenly awakened. Another patient (case 17) gradually regained consciousness after thirty-six days. Hemiparesis was also slow to improve,

the patient never suddenly regaining use of the affected side. One patient (case 29) continued to have spasticity for several weeks. Aphasia disappeared by the time of discharge in four patients, but the fifth patient was still aphasic on leaving the hospital on the thirtieth day after injury. In one patient the disks returned to normal soon after surgical drainage of the cerebrospinal fluid. In the other the disks were normal eight months after operation.

No postoperative spinal punctures were done on four patients (owing either to freedom from symptoms on the part of the patient or to the fact that at that time the value of postoperative drainage was not realized). One puncture was done on each of two patients, one six days later, when the pressure was 280 mm., and the other forty-eight days later, when the pressure was found to be 200 mm. Two spinal punctures were done on one patient, the pressures being 400 and 60 mm. Four or more spinal punctures were done on five patients. The last group show particularly well the value of postoperative spinal drainage. A brief history of each case will be given.

CASE 29.—This case was unusual in that despite normal cerebrospinal fluid the clinical course was downward and localizing signs became more pronounced. After operation there was profuse subdural drainage for two days. However, on the fifth postoperative day the pressure was 180 mm. The patient remained in coma and in about the same general condition. On the fourteenth postoperative day the pressure was again found to be 180 mm., and 28 cc. of fluid was withdrawn. The next day the patient became conscious. I am unable to explain the low pressure before operation. It was possibly due to an error in technic. It was clear that the patient did not do well postoperatively until repeated spinal punctures were done and the increased pressure reduced by withdrawal of from 28 to 40 cc. per day.

CASE 30.—Preoperatively the patient had severe headache, vertigo and delirium at times. Spinal fluid pressures were 315, 350 and 435 mm., the fluid showing 0.35 per cent and 0.05 per cent of blood and at another time being "deep yellow." After operation the patient continued to be irrational and stuporous, with considerable headache. There was much subdural drainage for one or two days. The wound later became infected, but no more cerebrospinal fluid drained. Spinal fluid pressures continued to range from 250 to 350 mm. for three days, then the pressure was 160 mm., when the patient became much less confused, and by the eleventh postoperative day, during which time five punctures were done, withdrawing 36, 18, 30, 20 and 40 cc. of fluid, the patient became entirely conscious. The fluid correspondingly became bright yellow and then clear. The pulse preoperatively was in the sixties and occasionally seventies. Postoperatively, it was from 74 to 114, most of the time in the eighties and nineties, and never in the sixties.

This is an excellent example of continued postoperative coma and high pressure, both of which were improved by spinal drainage.

CASE 22.—Preoperatively, although the spinal pressure was approaching normal from 300 to 175 mm., the patient's coma deepened, and it was thought that there

must be some operable lesion. At operation a large amount of yellow fluid was found subdurally under markedly increased pressure. The brain collapsed as this was drained. Postoperatively the pressure was as high as 200 mm., and it was necessary to withdraw from 20 to 45 cc. of fluid on six successive punctures before the pressure remained normal. The patient died later of pneumonia; at postmortem examination the brain showed no gross lesion and no excessive amount of subdural fluid.

CASE 11.—Preoperatively there was deepening coma and right hemiparesis on the third day despite four spinal punctures in two days and another on the third day, pressures of 400, 400, 200, 350 and 300 mm. being obtained with the withdrawal of 45, 45, 25, 30 and 35 cc. of fluid. At operation a large amount of subdural clot and blood-tinged fluid was found under increased pressure; there were also severe cortical contusions and subpial hemorrhage. Postoperatively the pressure continued to range from 280 to 400 mm. for six days with drainage of from 25 to 70 cc. of fluid. Coma continued until after the pressure became 140 and 150 mm., when the patient became more rational.

This is an excellent case to illustrate that although spinal punctures were not sufficient preoperatively, neither was operation alone sufficient. It was only after further repeated spinal punctures, bringing the pressure to normal, that the patient began to arouse.

CASE 31.—This case is a most excellent example of the efficiency of postoperative spinal drainage. Preoperatively there was deep coma. The pressure was 400 mm., and the fluid was very red with blood. Hemiparesis and anisocoria developed on the third day. At operation an extradural hematoma was found, and in addition an excess of free fluid subdurally, cortical contusion and intracortical hemorrhage. Postoperatively the coma was less profound but continued for fifty-two days; then within two days the patient suddenly improved and awakened completely, was entirely rational and symptomless and told of a dream he had had of being confined in a straight-jacket and for many days cruising over Siberia. Spinal fluid pressures were 400 mm. on the third postoperative day and 400 mm. on the sixth and seventh postoperative days. At these times 60, 55 and 50 cc. of fluid were drained, and on the eighth day pressure was only 75 mm.! After a "no drainage interval" of ten days the pressures were 200, 200, 325, 300 and 325 mm. on successive days, and the decompression area still bulged. After another "no drainage interval" of six days, successive pressures were 400, 400, 350, 400 50 and 300 mm. The amounts drained varied from 30 to 52 cc. Further evidence of continued postoperative pressure was the bulging decompression area. The fluid at first was very bloody, but became and remained clear after the fifth puncture. In this case inevitable death from extradural hemorrhage was prevented by operation; however, cerebral "edema" continued throughout the period of coma, at times returning to normal on successive punctures, but with marked "secondary rises" after "no drainage intervals." It is questionable if the patient would have survived the long-continued cerebral compression from excessive cerebrospinal fluid had not repeated drainages been done. Another feature was that there was apparent freedom from mental impairment after fifty-two days of coma and periods of high intracranial pressure.

SUMMARY

1. By far the most common lesion found at operation was a subdural and subarachnoid accumulation of fluid.

2. In most cases spinal drainage controlled the symptoms and signs of pressure. In a few others the patient responded well to surgical (subtemporal) drainage.

3. Preoperatively, the degree of pressure symptoms and consciousness were closely paralleled by the spinal fluid pressure.

4. Postoperatively, continued coma and pressure signs were present in the majority of cases. These were markedly improved when intracranial pressure was controlled by further repeated spinal fluid drainage.

CONCLUSIONS

1. Continued observation and accurate diagnosis of the intracranial lesion are absolutely essential in preoperative care and for determining when surgical intervention is indicated.

In addition to shock and medullary failure, spinal puncture is contraindicated in extradural hematoma; therefore, accurate diagnosis is the prerequisite to all treatment.

2. Spinal puncture with pressure readings and drainage is a valuable and indispensable adjunct to operation both preoperatively, for decompression and for determining the progress of increasing or decreasing intracranial pressure, and postoperatively, for decompression by repeated drainage.

GENERAL CONCLUSIONS

I have not described a control group of patients not having drainage of cerebrospinal fluid with which to compare the patients here presented. I cannot be positive that repeated drainage does not after a time predispose to increased secretion of cerebrospinal fluid and thus tend to sustain increased pressure. However, under this treatment I have found: (1) frequent and immediate improvement in clinical signs, (2) a corresponding fall in pressure and improvement in clinical signs and symptoms, (3) secondary rises in pressure with recurrence of symptoms after "no drainage intervals," (4) sustained pressure and symptoms after a delay in treatment and (5) a shortened postoperative course by postoperative spinal drainage.

The foregoing clinical facts all point to the therapeutic value of spinal drainage in a large percentage of cases of increased intracranial pressure after concussion of the brain.

A further word is here appended. Too frequently the surgeon is interested only in the patient with a severe injury to the head or in the patient whose injury will necessitate operation. I appeal for an equally keen interest in the patient who sustains only minor concussion, perhaps not even causing loss of consciousness, for in this type of injury, too, much can be done in controlling intracranial pressure.

BIOMECHANICAL STUDIES OF FIBROUS TISSUES APPLIED TO FASCIAL SURGERY

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The purpose of this thesis is to present the results of determinations of the tensile strength, elasticity and proportional limit of selected fibrous mammalian tissues and to apply the findings to the solution of clinical problems. These determinations were made by utilizing engineering methods, and the results are graphically portrayed with a tabulation of any variation. A representative cross-section of adult mammalians were studied, including rabbits, sheep, goats, dogs and man. Similar studies were also made on the young of the same species, and variations in the findings were contrasted with those noted in the study of adults of the same species, but these are not included in the present report. From each species representative fibrous tissues, particularly tendons and fasciae, were studied. In making the latter selection, tissues were chosen that were commonly used in transplantation and also that were involved in the syndrome of pain low in the back.

Adaptations of engineering methods permitted the graphic portrayal of the three physical properties selected. It was discovered that the fibrous tissues of mammalians possess physical properties that are comparatively similar. This made the findings of this research and also many other researches conducted on animals pertinent to man. Determinations for normal adults were established (fig. 4), and the variations in all tests from these normal findings were graphically portrayed (fig. 3). The biomechanical tests and histologic studies which

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Presented as a thesis to the American Orthopedic Association in 1934. Presented in part before (1) the Society of Plastic and Reconstructive Surgery in Atlantic City, N. J., June 1935; (2) the New York Academy of Medicine, Section of Orthopedic Surgery, and the Philadelphia Orthopedic Club at a joint meeting at the New York Academy of Medicine in November 1935, and (3) the American Society for the Study of Arthritis in New York, December 1936. Portions of the material were also shown as a scientific exhibit before (1) the American Congress of Physical Therapy in September 1935 and September 1936, (2) the Medical Society of the State of New York in April 1936, (3) the American Medical Association in May 1936 and (4) the Graduate Fortnight on Trauma at the New York Academy of Medicine in October 1936.

have been completed show that the physical properties of tendons and those of fasciae are comparatively similar, thus making the research and clinical work on surgical procedures on tendons at least partially applicable to those on fasciae.

Variations from normal determinations due to shear phenomena and trauma were studied and the variations graphically portrayed (fig. 9). Shear and trauma were regarded as being the underlying causes of many of the unsatisfactory results in operations on fasciae, particularly in the transplantation of fibrous tissues. Variations in placing prepared sutures and in removing, handling and placing living sutures introduce shearing stresses, with resulting damage to the fibrous tissues repaired.

The rôle of trauma and shear in pain low in the back is also briefly presented not only in relation to the fibers themselves but in relation to the mesothelium covering of the fibers. The mesothelial cells covering the fibers are in intimate contact with the nerves and blood vessels traversing the fascial spaces. It is believed that radicular pain following a definite nerve distribution, such as sciatica, may in certain cases be caused by disturbed functions of the mesothelial cells, with resulting impingement on the nerves in locomotion.

The clinical value of these determinations in operations involving fasciae will depend primarily on the knowledge of the normal and deranged functions of the fascial planes. The methods and technic now used may be supplemented rather than replaced by the clinical application of these data.

SELECTION OF TISSUES AND ANIMALS FOR STUDY

While fibrous tissue in greater or less degree is found in all organs, it predominates in certain locations. Where support is the chief function, fascia develops; where special adaptations of form become necessary for the transmission of power from the muscles to their respective insertions in other portions of the locomotor apparatus, tendons and ligaments are found. Representative structures of these groups were studied biomechanically. The data obtained should simplify the study of fibrous tissues in other locations. The anatomic studies of fascia by Gallaudet [1] and Davies [2] deserve particular mention.

The fascial planes vary in thickness according to their location and function and invest the higher structures, i. e., muscles, cords, tendons, bursae, vessels, nerves, viscera and joints and even cartilage and bone.

1. Gallaudet, B. B.: A Description of the Planes of Fascia of the Human Body, New York, Columbia University Press, 1931.

2. Davies, J. W.: Abdominal and Pelvic Fasciae with Surgical Applications, Surg., Gynec. & Obst. **54**:495-504, 1932.

There are two principal planes of fascia: the subserous and the subcutaneous. Since fascia is subjected to varying factors of stress, its final adult form has probably been determined by functional variations. Fascia lata was selected for the study of the fascial planes because of its importance in pain low in the back and because of its extensive use in the transplantation of living sutures.

The function of fascia lata is muscular support as well as the transmission of varying directional stresses in the thigh, and it conforms histologically to these functions, being a composite of fibers arranged in varying planes.

In the second group of fibrous connective tissues the tendons seemed the logical choice. Their prime function is the transmission of power developed in the muscles to their osseous insertions. The tendo Achillis would be expected to show adaptations of form corresponding to the simplicity of its action.

Other tendons have a more complicated function. The flexor digitorum longus transmits power around one joint to multiple osseous insertions. As the function is necessarily more complex, it would be expected that its structure is more complicated than that of the tendo Achillis.

The fourth tissue studied, the erector spinae, has a supportive rather than a kinetic function and is of prime importance in pain low in the back. Work on these four structures comprise test data presented on experimental animals, which were the rabbit, dog, sheep and goat. The weight range of these animals was from 1.8 to 58 Kg.

Work was also done on the human patellar ligament, which has a direct attachment between two bones, and on the quadriceps tendon, the attachment of which is between its muscle through a sesamoid bone to the tibia. Among other tissues studied were the aponeurosis of the external oblique muscle and the central tendon of the diaphragm.

NOTES ON HUMAN TISSUE

The preliminary report was based on test pieces removed from patients at the time of operation.[3] Since it is practically impossible to obtain sufficient living material for any extensive work on human tissue, animals were used for the development and standardization of the technic, and normals were determined for these. The human tissue obtained was used to confirm rather than to develop such data, and it was deemed advisable to regard the human tissues as only comparatively normal.

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3. Gratz, C. M.: Tensile Strength and Elasticity Tests on Human Fascia Lata, J. Bone & Joint Surg. **13**:534-540, 1931.

SELECTION AND DEFINITIONS OF MECHANICAL PROPERTIES

Engineers characterize the strength of elastic diaphragms, such as the tissues under consideration, as "tensile stress and shearing stress." These tissues cannot carry compressive, bending or torsional loads. Tensile stress results from the application of load which is parallel to the direction of the fibers. When the load is in excess of the strength of the tissue, the fibers rupture. This point marks the maximum tensile strength of the tissue.

When stress is not parallel to the direction of the fibers, a shearing stress results. This is caused by forces tending to slide one particle over the other. When a load acts in a direction not parallel to the fibers, there is a combination of shearing stress and tensile stress.

Elasticity.—Elasticity is that property of a body which causes it to resist deformation and afterward recover its original size and shape. The popular conception of elasticity is "stretchability" (as exemplified by rubber). This conception would give the impression of ability to change form, whereas the engineer understands elasticity not as the extent of stretchability but rather as the degree of recovery of original form. To illustrate, if identical unit areas of rubber and steel are subjected to the same amount of stress, the rubber will stretch more, but the resistance of the steel will be greater and with the release of stress it will return more nearly to its original form. Therefore, the elasticity of steel is greater than that of rubber. The standard measure of elasticity is in terms of Young's modulus. The importance of these definitions in this study cannot be too strongly emphasized.

Comment.—Theoretically, it should be possible to determine the elongation of tissues under stress until the point of rupture. Practically, the determinations on the latter part of this scale when tearing begins to take place have been found to be more or less inaccurate. The initial range of elasticity is determined by the location of the point up to which the tissues are truly elastic. The engineering term used for such a point is "proportional limit." A practical term for the description of the initial range terminated by such a point in the case of biologic material would be the "physiologic range of elasticity." This range corresponds on the graphs to the length of the composite graphs plotted, and it will be noted that the uniformity extended to a load corresponding to 500 Kg. per square centimeter (7,100 pounds per square inch).

Of what practical value are the defining and measuring of this initial range of elasticity?

In inorganic materials stress may be applied up to this point and repeated without permanent damage. In biologic structures separation of the fibers follows the application of load in excess of this point, and repair is more difficult than in the case of steel and other structures

in which replacement is possible. Whether rupture takes place in fibrous tissues or a fracture occurs in osseous structures, the result depends on whether or not the load exceeds this range of elasticity.

If two persons are subjected to a similar degree of stress, permanent damage may be sustained by one, while the other may have only a trivial injury. In view of the importance of making a definite prognosis, a competent producing cause of this variation in the degree of injury sustained by two patients is of inestimable value. On the basis of the engineering definition, the physiologic range of elasticity would have been exceeded in the first patient but not in the second. In the first patient the tissues would have lost their power of recovery; in the second, this power would have been unimpaired.

Another clinical phenomenon that is difficult to comprehend is the resistance of tissues without injury to a comparatively large amount of stress, while permanent damage may follow a trifling injury. In this case there are a smaller number of variable factors to be considered than in the previous example, and the natural query is: "What relation has the amount of stress to the damage sustained?" The graphs show that where there is tensile stress alone the elastic limit is not reached as quickly as when a combination of shearing and tensile stress is present. Therefore, a comparatively smaller degree of trauma produces damage beyond recovery by exceeding the physiologic limit of elasticity, if a combination of the two types of stress exists.

TECHNIC

The detailed technic of the methods employed in testing tissue and the methods devised for presenting such data have already been presented.[4] A brief résumé only will be given here.

A Schopper strength tester was used for the determination of tensile properties. Special clamps and necessary changes were made in the machine for the type of tissues being tested. Special instruments and technic were necessary to determine the cross-section area of the test specimens. The test pieces were 15 mm. long, and their cross-section area usually varied between 1 and 3 sq. m. The load was applied, and the resultant elongation of the test specimens was read at regular intervals. The tests were carried to rupture of the fibers. The result of each test was tabulated in a test record and then plotted in graphic form.

When the test data were thus available, a system of graphs and charts rendered the data available for comparative study. Individual graphs comprising several tests on tissue from one animal were averaged and composite graphs thus obtained. The composite graphs from individual animals were again averaged for two or more animals of the same species, and resulting graphs were regarded as representative of the tissues of one structure from that species.

The details of individual composite graphs are shown in figure 1 for certain tests on the sheep and in figure 2 for certain tests on human tissues. The vertical

4. Gratz, C. M., and Blackberg, S. N.: Engineering Methods in Medical Research, Mechan. Engin. **57**:217-220, 1935.

lines represent the amount of load, and the horizontal lines, the amount of elongation from such a load. The metric system is used throughout, and the load is calculated in kilograms per square centimeter (multiply by 14.2 to change to pounds per square inch). The composite and representative graphs are plotted only to the physiologic limit of elasticity. Representative graphs are alone used in the final summaries (fig. 3), which comprise the data obtained from the study of normal adults. Remarkable similarity between the animals tested and the human material tested is shown by comparison of a representative graph of the species studied (fig. 4).

Comment.—The variations between the individual graphs portray the factors of error in the technic. The total range of all results has been tabulated, but space does not permit the publication of all the data.

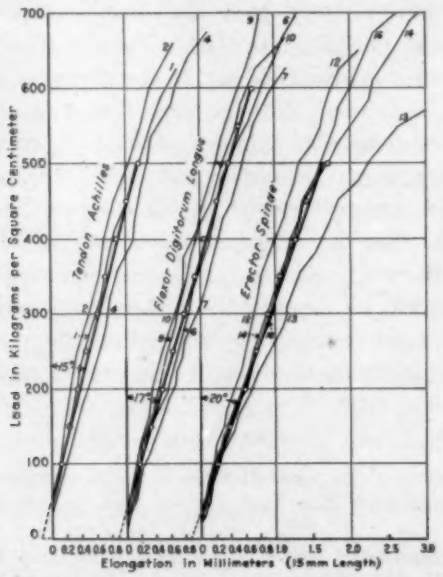

Fig. 1.—Tensile tests of fibrous tissues of an adult sheep.

When this work was commmenced, a variation of at least 30 per cent was expected, but much greater accuracy was obtained, the total range and variation between normal adults being in many cases less than 5 per cent.

The deductions made and the conclusions drawn from this study depend primarily on the accuracy of the data presented. All test pieces were prepared and all tests were made by me, with the subsequent preparation of graphs and charts. All data have been rechecked and approved by the workers who were associated with me.

As a result of these determinations on normal adults, the tensile strength, the elasticity and the physiologic range of the limit of elasticity of a representative cross-section of mammalians are now available

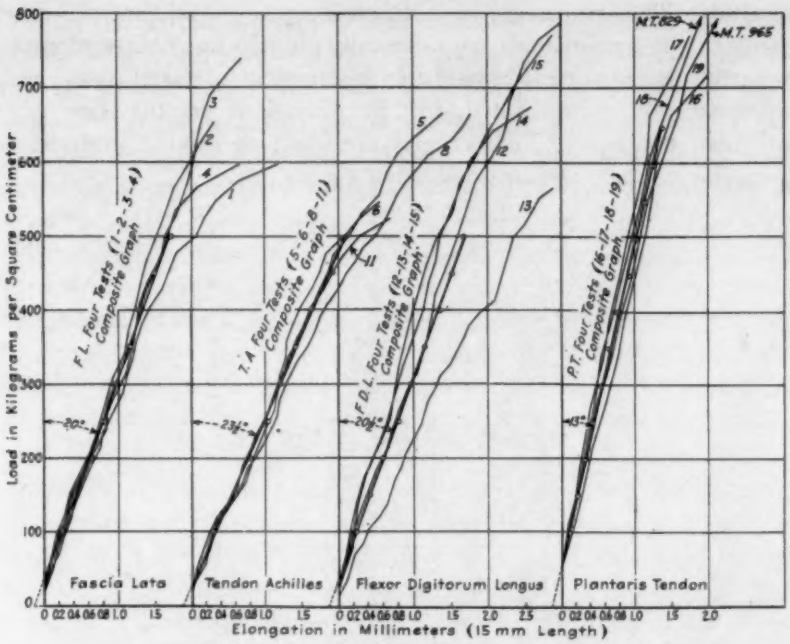
Load in Kilograms per Square Centimeter
Elongation in Millimeters (15 mm Length)
F.L. Four Tests (1-2-3-4) Composite Graph
T.A. Four Tests (5-6-8-11) Composite Graph
F.D.L. Four Tests (12-13-14-15) Composite Graph
P.T. Four Tests (16-17-18-19) Composite Graph
N.T. 829
N.T. 965
Fascia Lata
Tendon Achilles
Flexor Digitorum Longus
Plantaris Tendon

Fig. 2.—Tensile tests of the fibrous tissue of the human adult.

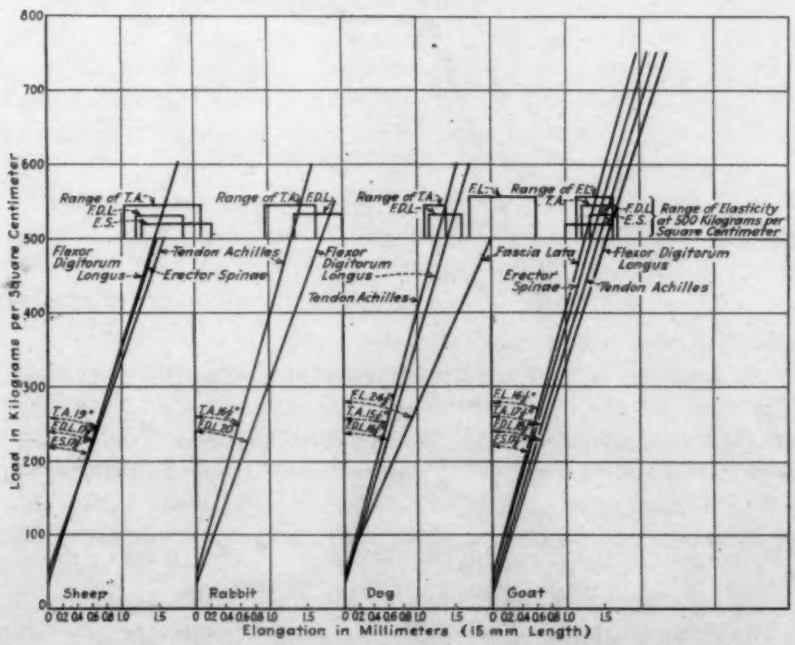

Fig. 3.—Summary chart of test data of species studied.

for study. The criteria are of sufficient accuracy to assume that fibrous tissues of the mammalians are essentially alike in these three physiologic properties under normal physiologic requirements. Variations in weight are apparently compensated for by variations in the size of the individual structures. Thus criteria are available for the study of variations due to shear, trauma and other causes.

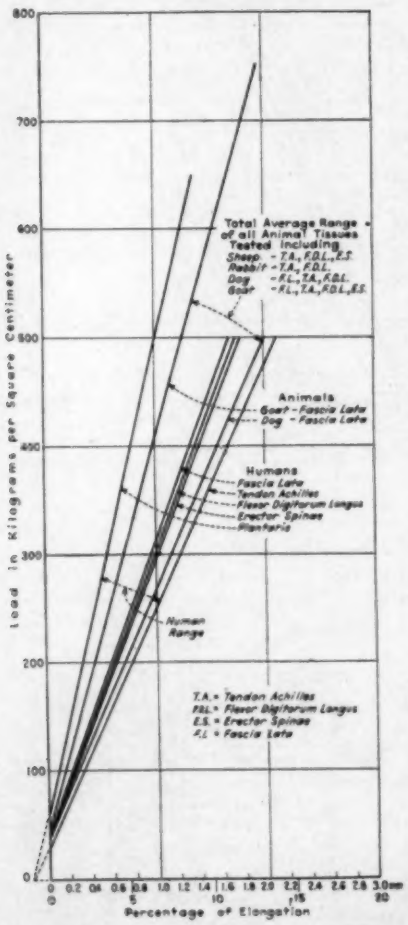

Fig. 4.—Summary of result of tensile tests of fibrous tissues. (Graphs are not plotted beyond proportional limit. Data from tissues resulting in curved graphs are not included.)

CLINICAL ADAPTATIONS OF STRENGTH, ELASTICITY AND PHYSIOLOGIC RANGE OF ELASTICITY

The determinations of strength, the elasticity and the physiologic range of elasticity now available on fibrous tissue of mammalians (including man) are of the utmost clinical value.

Tensile Strength.—Certain fibrous tissues were found to withstand stress up to a maximum of 1,476 Kg. per square centimeter (20,959 pounds per square inch). They have a specific gravity of approximately one-seventh that of steel and pound for pound approximate the tensile strength of structural materials. Clinically, however, findings of maximum tensile strength are of importance only if related to the function of these tissues.

Disturbances of the functions of tendons, particularly in the extremities, produce objective findings as well as symptoms and demand clinical study. When injuries to these tissues produce subjective symptoms alone, the diagnosis is difficult. That is particularly true of supportive fibrous tissue in less accessible portions of the body. Clinically, the tensile strength may be regarded as a graphic portrayal of adaptations to their function in body mechanics.

Elasticity.—It must be reemphasized that elasticity is the ability of a structure to withstand stress and to return to its original form after deformation. Of the tissues studied, it was considered that tendons were particularly designed for the transmission of power and that fascia had as its primary function support combined with kinesis. While there are differentiations between the two, they possess a high and markedly similar range of elasticity. Both require the ability to withstand stress and still maintain a relatively constant form. If such properties were not possessed by tendons and fascia, excessive variations in their form would result, leading to a disturbance of body mechanics. It may be noted in passing that the properties of supportive structures in quadrupeds, while in the same relative range, show an elasticity greater than in human beings.

The determinations of elasticity are of sufficient accuracy to be used in estimating the relative elasticity of other structures than the tendons and fascia. Such findings would be of tremendous clinical importance in relation to the circulatory system.

Physiologic Range of Elasticity.—The importance of proportional limits of elasticity was previously discussed; this is regarded as the terminal point in the physiologic range of elasticity. The tissues studied maintained their elasticity to a minimum tensile strength of 500 Kg. per square centimeter (7,100 pounds per square inch). Although the elasticity of many tissues exceeded this point, the fact that so high a minimum existed was one of the most important observations of the entire work.

Theoretically, if such tissues were subjected to a stress parallel to the direction of their fibers and if such force were within this limit, no separation of the fibers would take place. The determination of

this minimum range of elasticity makes available a definite point at which variations beyond the physiologic limit of elasticity may well be the long looked for explanation of the permanency of certain injuries.

Consistency of the Findings.—Figures 3 and 4 show that the similarity of animal and human tissue studied is remarkably consistent in tensile strength, elasticity and proportional limit. What does this consistency indicate?

These findings may be regarded as determinations of the mechanical form, just as histology is a study of minute structures and anatomy a study of the gross structure. As their functions probably determine their histologic and anatomic form, so in the same manner their functions probably determine the tensile and elastic properties. The paralleling of these studies indicates that any consideration of body mechanics should include study of the fibrous tissues from every angle.

The standard textbooks of anatomy contain scant discussion on the fibrous tissues, with the exception of the tendons. Comparative histologic studies of fibrous tissues are rare in English and American textbooks. The physiologist has accorded these tissues less study than he has the muscles. Finally, one might briefly review any book on traumatic or orthopedic surgery and compare the discussion on the osseous structures with that devoted to the surgery of the fascial planes. The functions of these tissues seemed to be relatively forgotten in mesodermal mechanics. A study of the fascial planes of any portion of the body, therefore, should when clinically applied lead to a marked improvement in the results of surgical treatment of the particular part selected. Kanavel's [5] study of the fascial spaces of the hand in relation to infection has completely revolutionized the clinical treatment of this member. In the words of Steindler: [6] "Unless we have a pretty clear conception of the functional mechanics of the soft structures which form part of the locomotor system we will not be able to go much further in the management of the legion of conditions which arise from the disturbances of these structures."

Application to Pain Low in the Back.—The preliminary report of the study of the functions of the fascial planes in relation to pain low in the back has already been made,[6] and the findings so reported have been clinically applied since April 1935. Clinically it is believed that impaired functions of the fascial planes of the lower part of the back and the thigh may be caused by fascial adhesions interfering with the normal translatory motion of the muscles which the planes enclose and secondarily involving the nerves.

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5. Kanavel, Allen B.: Infections of the Hand, Philadelphia, Lea & Febiger, 1925. Steindler, Arthur, in discussion on Gratz.[6]

6. Gratz, C. M.: Biomechanics: A New Method of Studying Physical Disabilities, Arch. Phys. Therapy **17**:145-150, 1936.

The tissues selected for the biomechanical study of this work included the erector spinae and also the fascia lata. Histologically, variations (figs. 5 and 6) in the arrangement of the fibers of these two tissues were noted. It was found, however, that these tissues, like tendons, were covered with a mesothelial layer of cells (fig. 6). This is regarded as a functional adaptation of the fascial planes, permitting movements between groups of muscles which they enclose. The fascial

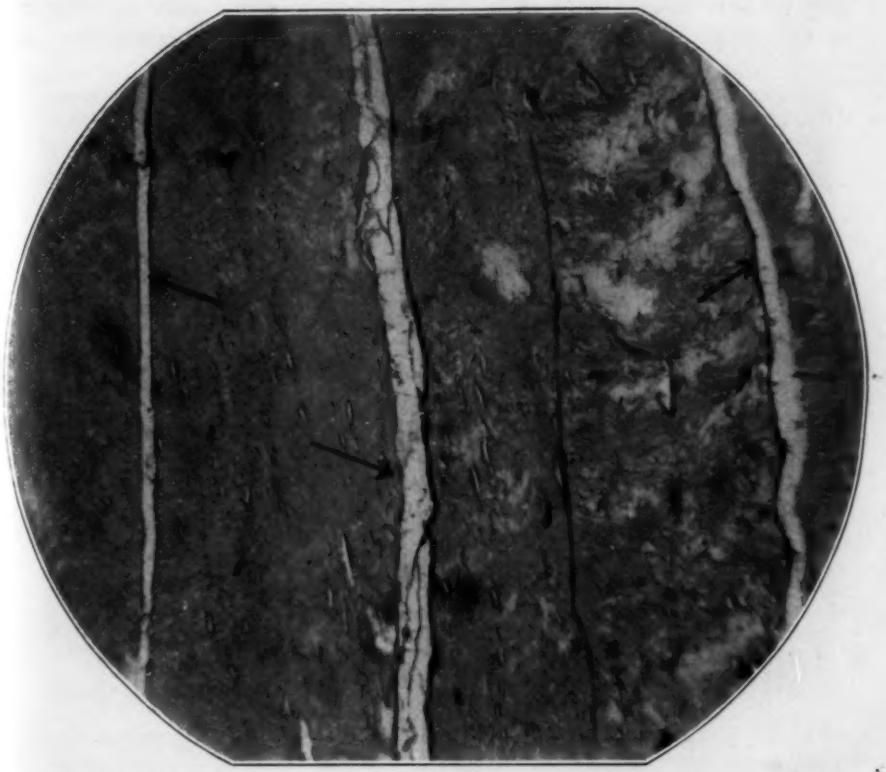

Fig. 5.—Photomicrograph of the human erector spinae. The heavy fibrous bands are shown and also the spaces between them. The fascial bundles are approximately parallel to one another.

spaces thus form joints between muscles (fig. 7) which transmit nerves and blood vessels from the central nervous system and the heart to the periphery of the body.

The lymphatic circulation is also intimately connected with the fascial spaces. This may be of vast importance not only in acute infections but in chronic rheumatic and arthritic conditions. The strength of the fibers of fascia thus serves to protect the nerves and blood vessels in addition to transmitting power between mesodermal

tissues. In normal locomotion these functions are probably performed with an adequate factor of safety. Anatomic studies on cadavers [6] in which air was injected into the fascial spaces showed free gliding motion between the nerves and the fascial spaces surrounding them. Anatomic studies on other cadavers (fig. 8) showed firm adhesions between the nerves and their fascial covering, which were easily demonstrated and photographed by using the same technic. Histologic studies on the mesothelial cells of arthritic patients showed a variation in the form of these cells which may correspond to the impaired functions of the muscles and the pain which these

Fig. 6.—The mesothelial covering of fascial fibers. Photomicrograph of normal human fascia lata (from the lower part of the thigh, a man, 32 years of age). Between the fibrous tissue bundles delicate strands may be seen. These are lined by flattened mesothelial cells. Parallel fibers will be noted in certain sections, and the central portion of the photomicrograph shows strands of fibers with an irregular arrangement.

patients had on normal movements. Hence it is believed that fascial adhesions may be the cause of limitation of motion and also of pain in certain cases of pain low in the back and of sciatica. Following the same technic as was developed in this research, air has been used clinically as a contrast medium to visualize the fascial spaces.[7] Such

7. Gratz, C. M.: Air Injection of the Fascial Spaces: A New Method of Soft Tissue Roentgenography, Am. J. Roentgenol. **35**:750-751, 1936.

roentgenograms are technically known as pneumofasciagrams. Roentgenographic variations between the normal and the arthritic patient have been noted which are believed to be due to fascial adhesions.

By the method described it has been possible to correlate this entire research work and combine it with roentgenographic studies for a new approach to the study of pain low in the back. Therapeutically, it was noted that the injection of air into the fascial spaces produced an increased range of motion of the parts treated. When this had been done in highly selected cases and combined with muscle training and physical therapy, the increased range of motion persisted. In addition, a gratifying relief from symptoms was obtained. This method of study has been regarded as being primarily largely diagnostic, but a working

Fig. 7.—The fascial joint between the gluteus muscles. The mesothelial covering of the fascia is shown as the fascial plane is held backward by the clamps. A bursa is noted between the two fascial planes.

report of the clinical features of this method of treating fascial adhesions is now being prepared. It is believed that this method, when perfected, will aid in localizing the pathologic process causing the symptoms and thus add to the accuracy of the surgical approach for its correction.

The rôle of trauma as the causative factor of pain low in the back and arthritis has been most difficult to explain, and in medicolegal cases particularly its importance is very great. A careful study of certain of these cases in which the foregoing concepts were used has led me personally to believe that trauma, particularly if it results in a shearing force, may tear certain fibers in the lower part of the back

or thigh and produce a secondary effect on the nerves transversing the fascial spaces. It should, however, be emphasized that the clinical applications of the concepts are not as yet sufficiently perfected to warrant general application and that injections into the fascial spaces for diagnostic and therapeutic purposes should be made only after a most thorough study of the anatomy of these spaces and a most careful clinical examination of the patient. The dangers of infection and embolism should be constantly in mind. Correlation of these studies with clinical procedures devised by other clinicians for treatment of pain low in the back and sciatica are discussed later in this paper. A remarkable similarity exists with the work of Penfield [7a] in his treatment of post-

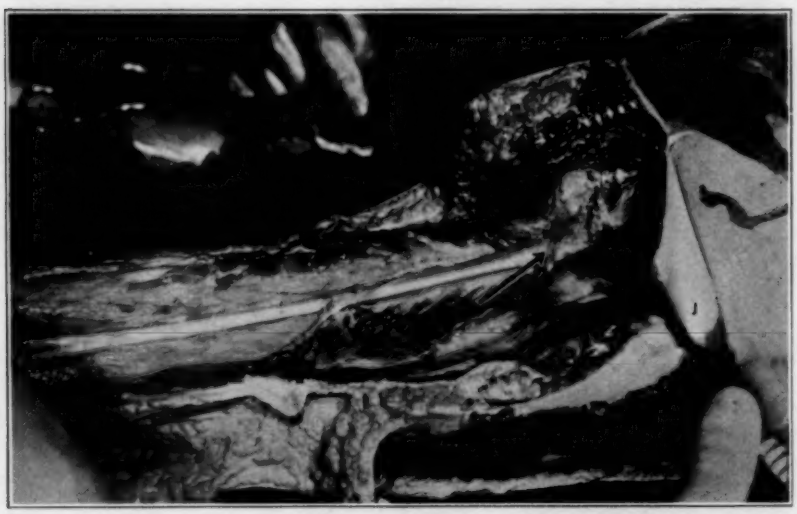

Fig. 8.—Adhesions involving the sciatic nerve. Air was injected into the fascial planes of this cadaver before dissection. Firm adhesions across the sciatic nerve are noted at the point shown by the arrow. There is bulging of the fascial covering of the sciatic nerve on either side of the adhesions.

traumatic headache by lumbar insufflation of air. His belief that "the abnormality, whatever it is, is obviously a mechanical one" and his mention of fine meningeal adhesions closely parallels the present explanation of obscure pain elsewhere.

7a. Penfield, Wilder: Chronic Meningeal (Post-Traumatic) Headache and Its Specific Treatment by Lumbar Air Insufflation; Encephalography, Surg., Gynec. & Obst. **45**:747-759, 1927. Penfield, Wilder, and Norcross, Nathan C.: Subdural Traction and Posttraumatic Headache, Arch. Neurol. & Psychiat. **36**: 75-94 (July) 1936.

VARIATIONS FROM NORMAL

The consistency of normal findings facilitated the study of forces causing variations from the normal.

Shear and Trauma.—Shear is a comparatively new word in surgery. In the literature reviewed Steindler's epoch-making book contained the only intensive study of the subject.[8] Shear has been studied by engineers for many years. The application of such a study to biologic material brings to light many findings of clinical value. Shear has been previously defined as being caused by any stress which tends to slide one portion of the test substance over the other. The engineering determinations are based on the study of inanimate objects.

Shear in biologic material should be of even greater interest, since the fibers in connective tissue depend for their nourishment on the cells between the individual fibers. Shearing stress would cause greater destruction of these cells than of the fibers themselves, thus causing more damage in biologic than in inanimate material. This fact adds to the interest of the study of shear in surgical procedures involving biologic tissues.

The normal being established, it is now possible to study shear phenomena and portray results graphically. These have been plotted in standard form and are shown in figure 9. Variations from the normal are so marked that definite conclusions would seem to be justified.

The first graphic portrayal of shear phenomenon is shown in figure 9*A*. All details of testing were the same except that the tissues tested were cut diagonally in increasing amounts from tests 1 to 6. This necessarily produced a shearing stress when load was applied in the direction of the arrows. The same phenomenon results when a living fibrous transplant is carelessly cut, the fibers not being parallel. Clinically, if fibrous tissues were securely fastened to two structures and then submitted to a stress not in the direction of the fibers, shear would result in addition to the tensile stress.

What is the effect on the physical properties of combining these two types of stress?

Figure 2 shows the average maximum tensile strength of the tendo Achillis to be 610 Kg. per square centimeter, with a maximum variation of 14 per cent. The maximum strength of the six pieces in which shear and tensile stress were combined varied between 165 and 428 Kg. per square centimeter. There is no regularity of elongation shown graphically by the lines. It is therefore impossible to obtain an average for results as was accomplished when tensile stress alone was studied. Tests 1 and 2 indicate that the tissues stretched irregularly and that

8. Steindler, Arthur: Mechanics of Normal and Pathological Locomotion in Man, Springfield, Ill., Charles C. Thomas, Publisher, 1935.

their maximum strength was far short of the normal. In the tissues of the remaining four tests the elongation was excessive and the maximum tensile strength much less. Thus, in the six combination stresses studied in this group no elastic limit was obtainable, and the physiologic range of elasticity was reduced to a vanishing point.

Various types of shear were studied, including transversely cut and irregularly cut specimens. In all cases there was marked variation in the elastic and tensile properties, and in none of these groups could a physiologic limit of elasticity be determined. It is therefore shown that combinations of shearing and tensile stress are a competent producing cause of permanent changes in the tissues even if a minimum

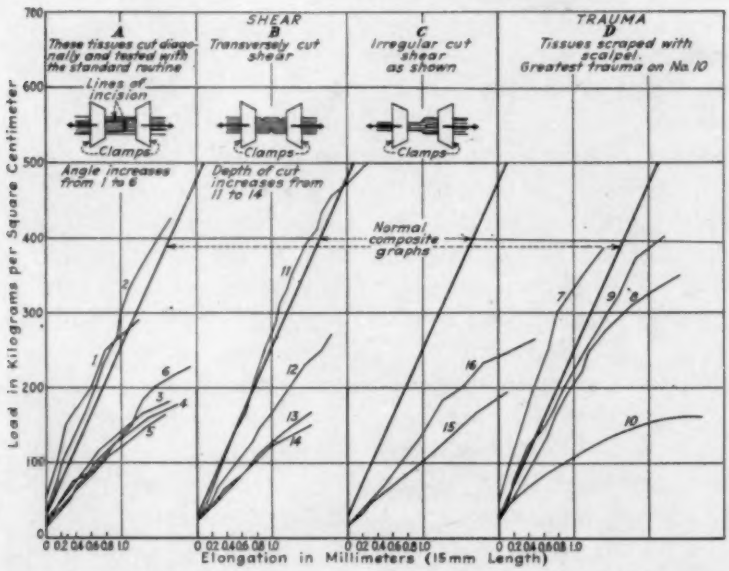

Fig. 9.—Graphic portrayal of the effects of shear and trauma on the human tendo Achillis of an adult.

of stress is applied. The extent of damage to tissues is proportional to variations in applying stress rather than to the amount of stress applied. These findings are of interest when applied to the erector spinae in pain low in the back and also in relation to the fasciae surrounding the sciatic nerve.

Shearing stress occurring in normal body mechanics would tend to produce marked damage to the tissues were the body not designed to counteract and minimize it. Since certain structures perform functions in various directions, fibrous tissues are logically so arranged as to perform these functions without the development of shear.

Microscopic sections of fascia lata (fig. 6) show a composite arrangement for such a purpose. Macroscopic examination of structures, such as a conjoined tendon, also shows a composite arrangement. These two are examples of function determining form and being arranged so as to avoid shear phenomena.

I shall consider the mechanics of the knee in the same terms as I have considered other structures. The quadriceps tendon and the patellar ligament transmit power in one plane only. How do these structures function when the knee is flexed? It would seem that forces pulling over the knee joint when in a flexed position would necessarily result in a shear phenomenon. Nature counteracts this through the structure of the patella. It will be found that the quadriceps tendon above and the patellar ligament below are attached to the patella so as to reduce to a minimum any shearing force. When a person is standing upright with considerable tension in the region of the knee, like a football player set to receive a pass, a shearing force is combined with tensile stress when such a person is "tackled." The result is a combination of tensile and of shearing stress and may explain the frequency of injuries in football players, particularly in the region of the knee.

Macroscopically, the structure of the sesamoid bones and the changes mentioned in certain tendons would seem to conform to nature's functional adaptation to eliminate or reduce the shear phenomenon. It would further seem that when the body is subjected to trauma which may result in a combination of tensile and of shearing stress such a combination may account for the severity in certain accidents.

Graphic portrayal of the effect of trauma is presented in figure 9 *D*. On reviewing the early tests it was found that the graphs showed all the effects of shear and trauma, as shown in this illustration. When the technic was revised and variations due to these two forces were reduced to a minimum, the normals presented were available. It is felt that the graphic portrayal of these two forces is a fair presentation of the effects of shear and trauma, as observed throughout the preparation of the entire work.

ADAPTATIONS IN REPARATIVE SURGERY

It must be remembered that the tissues studied are normally self-repairing and self-adjusting within certain limits. The physical properties of biologic material are regarded as being evolved in response to functional demands. The surgical adaptations are similarly considered in relation to the functions of repair and are correlated with this function. The monumental work of Hawley[9] in correlating surgical pro-

9. Hawley, George W.: Biological Basis of Surgery, Particularly Orthopedic Surgery, Am. J. Surg. **31**:438-453, 1936.

cedures with the biologic aspects of human tissue is particularly appropriate in guiding us in the application of these findings to clinical procedures.

Fibroplasia in the Process of Repair.—In the repair of muscles, fibrous tissue and bone, fibroplasia is noted in all three. It has been commonly observed microscopically that muscles repair themselves after injury by the formation of fibrous scar tissue. It is often found that the strength of such repair is greater than of the muscles themselves.

Fibroplasia is responsible for the unassisted repair of injured tendons and fasciae and occurs in the repair of osseous structures. Ackerson gave a detailed description of the sequence of mesodermal metaplasia after rupture of the supraspinatous tendon of the shoulder.

Fibrous tissue is formed in the unassisted repair of mesodermal deformities, and it is of interest to know that its formation in such localities parallels the normal development during growth. Wassermann,[10] citing Levy, said:

> In simple severing of the tendon the arrangement of the cells and fibers in the young germinal tissues, even in the transitional stage, corresponded to the traction forces which are the natural result of movements of the foot and leg through the action of the flexors of the thigh transmitted to the fascia and through simple stretching of the fascia. . . . Levy's work showed a second important fact, namely, that in the absence of traction on the young germinal tissue there is also quantitative reduction of connective tissue formation in comparison with that noted in simple severing of the tendon. . . . Levy observed that the tension in certain directions influenced the direction of growth of the cells and their form as they proceeded to grow; he also observed that this tension influenced the intensity of fibril formation. These findings Weiss corroborated in every detail. The fact that Triepel and Weiss agree seems especially important. . . . The conclusion is that we do not know to what extent mechanical demands play a part in genesis, but we are justified in assuming that the arrangement of the elastic fibers and the measure of their development are subject to the same influences as are similar processes in the non elastic elements of the connective tissue.

Fibroplasia in the normal process of repair of mesodermal structures and of the tissues so formed varies according to the functional demands on it in the same way as during normal growth. Surgical repair, which permits early application of tension and hence stimulates fibroplasia, could be expected to result in much more rapid return to normal function.

Fibroplasia in Surgical Repair.—The ultimate success of any reparative surgical procedure depends primarily on the permanency and strength of union between the coaptated tissues, assuming that the union is physiologically correct. The strength of such repair, if pre-

10. Wassermann, F.: Die Histogenese als abhangige Differenzierung in von Möllendorf, Wilhelm: Handbuch der mikroskopischen Anatomie des Menschen, Berlin, Julius Springer, 1929, vol. 1, pp. 727-735.

pared sutures are used after the first few days, depends on the newly formed fibrous tissues rather than on the sutures themselves. Howes [11] proved this and graphically portrayed the strength of the healing wound in relation to fibroplasia. What then is the function of prepared sutures?

Except during the first few days, the strength of repair does not depend on the sutures themselves. When nonabsorbable sutures are used they are found to coaptate the tissues for a variable length of time. If such sutures are inserted under tension, they cause definite changes in the tissues in which they are embedded. This may result in weakening of the suture line with corresponding inaccuracies in coaptation. This weakening will vary directly with the elasticity of tissues in which such sutures are placed; hence tension on the sutures may set up a vicious circle. Even if such sutures are advantageously placed, for the reasons stated they may prove insufficient to counteract the retraction of the muscles and fibrous tissue which they are required to hold.

Absorbable sutures play the same rôle, except that with their use there is the additional factor of progressive loss of tensile strength of varying intensity, which under certain circumstances may impair the coaptation of the tissues sutured. Both play a passive rôle, and their ability to hold the tissues is no greater than the strength of their host tissues. Therefore, as Howes suggested,[12] a definite technic of suturing should be developed which would reduce to a minimum any damage done to their host tissues.

The normal graphs contrasted with the shear graphs indicate what the ideal technic should be. If fibrous tissue is subjected to a stress not at right angles to its cross-section, excessive elongation of the structure occurs, with a resulting deformity or a pulling out of the suture. This is the fallacy of most of the methods of suturing which have been devised to repair tendons. Moreover, most sutures are inserted in such a manner that they play an entirely passive rôle in holding the tissues. The coaptation is seldom designed to withstand or even to approximate the original function of the tissues involved. A new method of repair embodying these principles is being published.

Theoretically, living sutures offer a greater possibility of establishing early approximation of fibrous tissues because they supply in part the mesodermal structure which must be regenerated. They may be safely held under tension and thus approximate the normal functions of the involved area. The fundamental difference between living sutures and

11. Howes, E. L.: Factors Determining the Loss of Strength of Catgut When Embedded in Tissue, J. A. M. A. **90**:530-532 (Feb. 18) 1928.

12. Howes, E. L.: Strength of Wound Sutures with Catgut and Silk, Surg., Gynec. & Obst. **57**:309-317, 1933.

prepared ones (either absorbable or nonabsorbable) is that the former take an active part in the desired union of the tissues, in contradistinction to the passive rôle of the prepared suture.

CLASSIFICATION AND SELECTION OF CASES FOR FASCIAL TRANSPLANTATION

Direct transplantation of fibrous tissue is indicated in cases in which the strength of fibroplasia may clinically be of insufficient strength. Such a method supplements the strength of fibroplasia with the strength of the transplant.

In the words of Neuhof and Hirschfeld:[13] "Fascial transplants offer a wider scope in reparative surgery and a greater field of usefulness than the other forms of transplantation." As the selection of cases for transplantation depends primarily on the strength of the repair needed, the comparative strength of the tissues involved would seem to be a logical guide to assist in selecting individual cases. Therefore, the problem resolves itself into a study of the processes of repair in bone, muscle and fibrous tissues in relation to their strength.

Study of the permutations and combinations between the groups of connective tissue structures should enable the surgeon to establish principles on which the selection of cases could be successfully based. Of the three groups, muscle has the weakest tensile properties, and bone the strongest, and the tensile properties of fibrous tissues lies between these two extremes.

Certain physical properties of fibrous tissues have now been determined and compared, thus assisting in such a selection. The six possible combinations arranged in relative order of strength are: (1) muscle to muscle, (2) muscle to fibrous tissue, (3) muscle to bone, (4) fibrous tissue to fibrous tissue, (5) fibrous tissue to bone and (6) bone to bone.

Fibroplasia between muscles is often stronger than the muscles themselves; so transplantation of any tissue should seldom be necessary except in cases in which there is a marked destruction of the muscle itself.

The strength of fibroplasia is frequently insufficient in the union between muscle and fibrous tissue. In certain cases of repair of hernia transplantation of fibrous tissue is indicated to replace tissues that are no longer present. In other cases tension is necessarily placed on the suture line. In both groups reenforcement of the repair by fibrous tissue transplantation is frequently indicated, especially in cases in which the hernia has recurred after treatment.

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13. Neuhof, Harold, and Hirschfeld, Samuel: The Transplantation of Tissues, New York, D. Appleton & Co., 1923.

In every organism muscle is attached to bone by fibrous tissue. When union is desired between muscle and bone, the transplantation of fibrous tissues for such repair would be physiologically correct in selected cases.

Is the transplantation of fibrous tissues to fibrous tissues the physiologic ideal? When tendons are severed, the tonus of the muscle to which they are attached and their own high elasticity may result in marked retraction. The tensile properties and elasticity which fibrous tissues have been shown to possess make them ideal for such a repair. The difficulties encountered in using prepared sutures have already been shown. Fibroplasia is usually of sufficient strength if operation is performed early, but in certain cases in which marked retraction has taken place reenforcement of the repair by transplanted tissues is frequently indicated.

Union between fibrous tissue and bone should be stronger than between fibrous tissues themselves. It is necessary, therefore, to secure a physiologic union sufficiently strong to withstand clinically the stress to which the union may be subjected. Transplanted fibrous tissue is the physiologic choice to supplement the strength of scar tissue in many cases.

In a few cases union between osseous structures may require tissues of greater tensile strength than that possessed by the fibrous tissues, and in such cases foreign material or bone grafts have frequently proved successful. The splendid work of Albee,[14] based on sound biologic principles, has solved many of the difficulties previously encountered in this group. In certain cases transplantation of fibrous tissue is indicated[15] as a supplement to plastic repair of bone. In the evolution of joints, fibrous tissues are developed. Therefore, in cases in which union is desired or in which reenforcement of joints with motion is required, transplantation of fibrous tissue would seem to be physiologically indicated. The high tensile strength which fibrous tissues have been shown to possess indicates that the possibilities of using them in plastic repair of bone are just beginning to be realized.

The variable tensile strength necessary in repair requires a variety of methods to achieve permanent results. The strength of the tissues coaptated would be weakest in union between muscle and muscle and strongest between bone and bone. In cases of the former type transplantation of any tissue is seldom indicated, whereas in certain cases of the latter group a bone graft or even foreign material may be required to supplement the strength of repair.

14. Albee, Fred H.: Orthopedic and Reconstruction Surgery, Philadelphia, W. B. Saunders Company, 1921.

15. Gratz, C. M., and Robison, Richard P.: Living Sutures as a Supplement to Plastic Bone Surgery, Am. J. Surg. **26**:362-367, 1934.

Between these two extremes lie the group of cases in which transplantation of fibrous tissue is more commonly indicated. It should be emphasized, however, that the strength of any repair is no greater than the strength of the host tissues, and the method of repair should be so devised as to conform with the normal processes of repair which the body possesses.

From references already made to the metaplasia between mesodermal structures, it seems logical to assume that transplanted fibrous tissues would unite to bone, muscle and other fibrous tissues. Clinical work herewith reviewed shows the difficulties encountered and the progress made clinically in securing firm union between the transplant and these structures.

McArthur in 1901 [16] was one of the first successfully to transplant fibrous tissues for surgical repair. Kleinschmidt [17] did a large amount of experimental work on the transplantation of fascia. He used three groups of rabbits, twenty-three animals in all, and showed that fascia remained alive and showed changes in its structures in response to the functional demands made on it. This observation was of profound significance as it showed that the transplanted tissue paralleled fibroplasia and fibrous tissue formed during normal growth.

Kleinschmidt also advised the longitudinal insertion of the fascial tissues and made the important observation that when transplants were placed beneath the skin, where they were not subject to tension, they showed little replacement.

Unfortunately, the early surgical technic did not strictly conform to the physiologic principles enunciated by these workers. Patch transplants were generally used and held in position by prepared sutures. Such transplants were not cut parallel to the fibers. On the application of stress after transplantation a combination of shearing stress and tensile stress may result in disintegration of the transplant. This would parallel the shear phenomenon graphically shown in figure 9 and would account for the partial failure of many patch transplantations.

Gallie and LeMesurier [18] noted that in certain cases firm union resulted between fibrous tissues and bone in their operation for tenodesis. In other cases separation occurred between tendon and bone. As a result of these observations, they used fibrous tissues cut parallel to

16. McArthur, L. L.: Autoplastic Suture in Hernia and Other Diastases, J. A. M. A. **37**:1162-1165 (Nov. 2) 1901.

17. Kleinschmidt, O.: Experimental Investigations Concerning the Histological Changes in Structures in Freely Transplanted Fascia Lata and Proof of the Viability of This Tissue as Shown by Vital Staining, Arch. f. klin. Chir. **104**: 933-954, 1914.

18. Gallie, W. E., and LeMesurier, A. B.: The Transplantation of the Fibrous Tissues in the Repair of Anatomical Defects, Brit. J. Surg. **12**:289-320, 1924.

the direction of the fibers as a suture. The technic became known as living suture surgery. All fat and fibrous tissues were removed, as these interfered with the formation of lymphatics around the transplant, cutting off the lymphatic supply. Trauma during transplantation was reduced by the use of special instruments. Shear phenomena were thus minimized, and the growth of the transplant facilitated in its new position. The work of Gallie and LeMesurier [18] greatly improved the results in transplantation of fibrous tissue, and many new fields were opened for its use.

The present status of living suture surgery is concisely stated by Bunnell [19] on the basis of his vast clinical experience: "Free grafts of fascia and tendon have normal appearance and normal function over years, and hypertrophy in response to use. They grow solidly to bone, muscle and tendon, if properly contacted." The requisites of proper contacting of the transplanted tissues in the terms which are being used will be fully described later.

What clinical results have been attained in the groups before mentioned? A review of the literature has disclosed no report of a case in which transplantation has been necessary in repairing defects in the muscles themselves.

The surgical repair of hernia requires union between muscle and fibrous tissue. Living sutures have proved most successful in this type of repair. The work reported by Gallie and LeMesurier and also by Coley and Burke [20] deserves particular mention. Success has been achieved in the treatment of recurring hernia and in cases in which large transplantations are required to replace tissues no longer present.

In the union of muscle to bone one brilliant example of using a large transplant is the operation of Mayer [21] by which a paralyzed deltoid muscle is replaced by the action of the trapezius muscle. Fascia lata is attached to this muscle, transmitting its power to its desired insertion in the humerus.

Living sutures have been particularly advantageous when used to repair defects in the fibrous tissues themselves. The clinical achievements of Gallie and LeMesurier [18] and of Bunnell [19] are noteworthy con-

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19. Bunnell, S.: Fascial Graft for Dislocation of Acromioclavicular Joint, Surg., Gynec. & Obst. **46**:563-564, 1928.

20. Coley, B. L., and Burke, E.: Operative Treatment of Hernia by Living Sutures, Am. J. Surg. **2**:1-10, 1927.

21. Mayer, Leo: Physiological Methods of Tendon Transplantation, Surg., Gynec. & Obst. **22**:182-197, 1916; Physiological Method of Tendon Transplantation, ibid. **33**:528-543, 1921; Transplantation of the Trapezius for Paralysis of the Abductors of the Arm, J. Bone & Joint Surg. **9**:412-420, 1927.

tributions in this field. The experimental work of Mason and Shearon [22] also deserves particular attention.

Union between fibrous tissue and bone was first noted in Gallie and LeMesurier's [18] work on tenodesis. The transplantation of tendons to new osseous insertions has also proved clinically successful. Repair or transplantation of tendons in the lower extremities must be strong enough to transmit the necessary stresses in weight bearing. Transplants of fibrous tissue have been shown to be of sufficient tensile strength to repair ruptured patellar ligaments and quadriceps tendon, in which case the sutures are embedded in the tibia or patella on one side and in the ligaments on the other.

When union is desired between osseous structures, living sutures have been used to supplement bone grafts and also independently. Patterson [23] has employed fascia lata to supplement plastic repair of the tibia and has also made use of the same tissue without bone graft. Ober's [24] operation for repair of a fracture of the patella utilizes quadriceps tendon. Transplantation of fibrous tissue has also proved of value in reenforcing joints and repairing dislocations of bone. The work of Henderson,[25] Gallie and LeMesurier,[18] Nicola [26] and myself [27] for the surgical repair of recurring dislocation gives clinical examples. The technic of Bunnell [19] in repairing separation of the acromioclavicular joint is another example.

These examples show the successful use of transplantation in certain of the groups mentioned and may assist in selecting cases for transplantation. The fundamental data presented on the relative strength of tissues may be of aid in determining not only the strength of the transplant but that of the tissues in which it is embedded.

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22. Mason, M. L., and Shearon, C.: Process of Tendon Repair: Experimental Study of Tendon Suture and Tendon Graft, Arch. Surg. **25**:615-692 (Oct.) 1932.

23. Patterson, R. H.: Internal Fixation of Fractures and Dislocation by Use of Human Fascial Suture, Ann. Surg. **88**:879-884, 1928.

24. Ober, Frank R.: Fracture of the Patella: New Operation, J. Bone & Joint Surg. **14**:640-642, 1932.

25. Henderson, M. S.: Habitual Dislocation of the Shoulder, J. A. M. A. **95**:1653-1658 (Nov. 29) 1930.

26. Nicola, T.: Recurrent Anterior Dislocation of the Shoulder: A New Operation, J. Bone & Joint Surg. **11**:128-132, 1929.

27. Gratz, C. M., and Robison, Richard P.: Intra-Articular Stabilization for Recurring Dislocation of the Shoulder: Technique of Suspension to Acromium by Autogenous Fascia Lata Suture, Am. J. Surg. **15**:71-74, 1932. Gratz, C. M.: Multiplex Graft Technique for Extra-Articular Arthrodesis of the Spine, Surg., Gynec. & Obst. **48**:119-123, 1929.

SELECTION OF TISSUES FOR TRANSPLANTATION

The literature shows that there is a marked divergence of opinion as to which fibrous tissues are most suitable for transplantation. Fascia lata has been most frequently used. Functionally, fascia lata is designed for the transmission of tensile stress in various directions. A suture is used for the transmission of stress in one direction only. Fascia lata showed the greatest variations, and the histologic study showed that its fibers were often compositely arranged. The natural conclusion would seem to be that its availability rather than its physical properties has governed its choice. Henderson [25] used fascia lata for tenosuspension of the shoulder, but later found it unsatisfactory and used peroneus longus tendon. Plantaris tendon has also been used successfully as a suture. The remarkable consistency of the physical properties of all the tissues studied shows that if the fibers are arranged parallel to one another they should be of approximately equal value for transplantation. A markedly composite structure would be expected to have poorer tensile properties than one with exactly parallel fibers. Almost all tendinous structures, including the erector spinae of the back and the aponeuroses of the external oblique muscle, have proved satisfactory. This finding enlarges the source of supply and suggests many new locations from which transplants can be obtained. It cannot, however, be emphasized too strongly that fibrous tissue should not be removed from locations where its removal might harm the patient.

It is always desirable to remove the suture from the site of operation, thus eliminating an additional incision and scar. The operation of Ober,[24] using the quadriceps tendon for the repair of a fractured patella, is an example of this. I have used a free graft of periosteum taken from the tibia to supplement a bone graft of the tibia. In this particular case there was recurring nonunion after a first bone graft, and the second operation was so designed that in addition to a powerful bone graft further physiologic security was given by the use of strips of periosteum as sutures to hold the bone graft in position.

Periosteum has comparatively poor tensile properties but was used to form a mesodermal bridge between the host and scion tissues with good result. I have also used the erector spinae tendon as a supplement to spinal graft of the lumbosacral angle and lumbar region of the spine. The experimental work of Levering,[28] based on the use of peritoneum and the suggestion that the sack be used in the repair of hernia, is one of the recent contributions in this field. The successful clinical use

28. Levering, J. Walter: The Use of Peritoneum in the Repair of Inguinal Hernia, Ann. Surg. **101**:550-553, 1935.

of the tendon of the triceps muscle to repair a fracture of the olecranon has been reported by Rombold.[29]

It is believed that an anatomic study of the fibrous tissues will permit the removal of the transplant from the site of the operation in many more locations than have been reported at the present time. Anatomic studies are already under way which may lead to future progress along these lines. It is of tremendous advantage to both the surgeon and the patient if an extra incision can be avoided.

However, the tensile strength of the transplant is only one of the many factors to be considered in selecting the suture. There is also a marked variation in the size of sutures that have been used. One of the smallest reported was a strip of aponeurosis of the external oblique muscle about 1/8 inch (2.5 mm.) in width (Adair[30]). In the study of the external oblique muscle it was found that the average thickness of this structure in the human beings studied was 0.2 mm.

Gallie and LeMesurier,[18] in the repair of the patellar ligament, removed a longitudinal half of the tendo Achillis and divided it into two portions, using each as a transplant. Basing my calculations on data obtained in preparing these tests, I found the approximate cross-section of such a suture to be at least 15 sq. mm., or about thirty times the size of the sutures used by Adair. In addition, the tensile properties of the tendo Achillis per unit area are much greater than those of the aponeurosis of the external oblique muscle. While these two examples are the extremes reported in the literature, it is realized that a great many factors, many of which have not yet been determined, will decide the exact size of the suture necessary.

Many surgeons have used sutures of intermediate size. Dutta[31] used a strip of the aponeurosis of the external oblique muscle 1.1 cm. in width for the repair of hernia. Barr[32] used fascia lata for the same operation and endeavored to have the strip about 1 cm. in width. Bunnell,[19] in the repair of separation of the acromioclavicular joint, used a strip of fascia lata about 1 cm. in width. Hodgkins[33] utilized a strip of fibrous tissue from the sheath of the rectus muscle about 6.5 mm. in width. Henderson[25] used the entire tendon of the peroneus longus

29. Rombold, Charles: A New Operative Treatment for Fracture of the Olecranon, J. Bone & Joint Surg. **16**:947-950, 1934.

30. Adair, F.: Use of Aponeurosis of External Oblique as Source of Living Suture for Inguinal Herniotomy, J. A. M. A. **82**:629-630 (Feb. 23) 1924.

31. Dutta, P. C.: Surgery of Fascial Transplantation with Illustrative Cases, Indian M. Gaz. **67**:326-330, 1932.

32. Barr, E. O.: Fascial Suture Repair of Hernia, Virginia M. Monthly **56**:328-330, 1929.

33. Hodgkins, E. M.: New Method of Inguinal Herniorrhapy with Living Fascial Sutures Obtained from Rectus Sheath, Surg., Gynec. & Obst. **47**:831-836. 1928.

muscle for tenosuspension of the shoulder. These examples are sufficient to show that there is a wide variation in the size of suture used.

SIZE OF A SUTURE

The study of the forces that cause variations in the strength of fibrous tissue as well as the comparative determinations of tensile properties gives definite aid to the surgeon in determining the size of a suture. Fascia lata and the sheath of the rectus muscle are composite tissues designed for transmission of stress in varying directions. A suture withstands stress in one direction only. Therefore, if composite tissues are used they must necessarily be larger than the tissues in which the fibers are parallel. The tendons and the erector spinae muscle have a parallel arrangement of their fibers and have been shown to have approximately the same strength per unit area. Therefore, they would be more uniform than composite tissues.

It is obviously impossible to measure the exact area of cross-section of a transplant before it is inserted. However, if the approximate thickness is known, the width may be estimated, giving a comparative approximation of the area of cross-section. The average thickness of the aponeurosis of the external oblique muscle is 0.2 mm.; that of fascia lata, 0.3 mm., and that of erector spinae muscle, 1 mm. A suture of erector spinae muscle one-fifth or one-third the width of the external oblique muscle and fascia lata, respectively, would posseses approximately the same tensile properties. In my opinion, strips of fascia lata should be between 5 and 10 mm. in width, and if greater strength is required, multiple sutures should be used. Sutures of erector spinae muscle between 1 and 2 mm. in width would usually be of sufficient strength for transplantation. These examples are given for comparison only, and the strength and size of sutures should always be considered in relation to the strength of the tissues in which they are embedded and in relation to the clinical stresses to which they will be subjected after transplantation. If a suture is placed in bone, a much heavier one can be used than could be placed in muscle.

The accuracy with which a suture is cut and placed is of even greater importance than its size. A large suture in which shear may develop on application of physiologic stress will be much less effective than a smaller one so prepared and placed as to reduce shear to a minimum. For the same reason, if the suture is traumatized in its handling, removing or placing, intrinsic changes may take place, which on the application of stress will produce the same type of phenomenon shown in figure 9. It might be wise at this point to reiterate that shear and trauma reduce the elastic limit, and on the application of stress such tissues may begin to disintegrate almost immediately. It is safe to

predict that as the clinical work on fascial transplantation progresses, the sutures will be of smaller size than those now used, but much greater attention will be paid to the selection and placing of such tissues.

OTHER FACTORS IN TRANSPLANTATION

The exact amount of any tissue that can be safely removed for transplantation at the present time depends largely on clinical observation. As knowledge concerning the relative strength of these tissues and determinations of a safety factor in body mechanics become available, it will be possible to have definite determinations to guide one in the amount of fibrous tissue that may safely be removed from certain portions of the body. In compensation work, particularly, many claims for disability may arise if too much tissue is removed, especially if an extra incision is made to obtain the transplant. Extra incisions necessarily add to the gravity of any operation, and the choice of method when more involved technic is necessary will depend in all cases on the surgeon.

The research work of Howes [11] shows that the tensile properties of prepared sutures decline rapidly after they are embedded in their host tissues, whereas the clinical work of Gallie and LeMesurier [18] and of Bunnell [19] shows that fascial transplants, if properly coaptated, retain their tensile properties indefinitely. A comparison of the physiologic strength of the two materials after transplantation is as yet impossible. The lymphatics are carried to the transplants through fibroplasia. The active rôle of the living suture transplant is in sharp contradiction to the passive rôle of the prepared suture. If the sutures are of excessive size or are rolled on themselves, their central portions may receive an inadequate supply, endangering their viability. The technic must lend itself to much more careful coaptation than for tissues supplied entirely by blood vessels.

No hard and fast rules are as yet justified, so that the selection of cases for transplantation, the determination of the kind of tissues to use and the size of the transplant must for the present at least be left to the clinical judgment of the surgeon. In each case there are many factors which will cause variation, and a few determinations of these are now available, although the few that have already been made have proved themselves invaluable.

ELASTICITY AND TENSION OF FIBROUS TISSUE

By referring to the summary in figures 3 and 4, included in the data, one will find that the entire group of fibrous tissues studied possess a relatively high elasticity. Individual variations are included in the

graphs for the respective tissues. The normal physiologic range of elasticity was maintained to a minimum stress of 500 Kg. per square centimeter.

On the basis of the original concepts of form in relation to function, little doubt can exist that the high elasticity of these tissues is a functional adaptation to maintain properly tonus and contour in fascial structures and to transmit power between the component members of the locomotor group. In the same way that the spinal column has the dual function of supporting the body and protecting the spinal cord, the fascial fibers have the dual function of supporting various structures and protecting the nerves and blood vessels in their course to the periphery. It is also logical to expect that these functions will be performed with an adequate factor of safety.

Such properties doubtless exist in a relative degree in tissues in which there is a smaller percentage of fibrous elements. The ideal application of these principles surgically would be to transplant fibrous tissues so that they could withstand stress closely approximating the normal physiologic range of elasticity and at the same time the viability of the transplant would not be endangered.

Determinations of elasticity during testing were available only when the tissues were held firmly in the clamps and when shear and trauma to these tissues had been eliminated. A parallel may be drawn in surgical technic. The transplant must be firmly anchored in its host tissue and so placed that physiologic stresses may be withstood with a minimum of shear. Variations in this procedure will produce intrinsic changes in the transplant.

A discussion of elasticity inevitably leads to discussion of the optimum tension of the transplant. Unfortunately, at present no determinations of normal tension are available. This statement is made with due deference to the work of Mayer [21] and after extensive personal experimentation. One should, therefore, endeavor to transplant living tissues at a tension approximating that of the normal tissue. Fascial transplantations permit insertion under tension, whereas prepared sutures seldom adapt themselves to this technic.

FAILURES IN TRANSPLANTATION

The successful transplantation may be regarded as one in which the process of repair, including the process of adaptation, results in complete return of physiologic function in a minimum time. Delayed convalescence could be caused by factors which would delay the process of repair, but the process of adaptation eventually results in a partial or complete resumption of function. Some of the more frequent causes of failure in transplantation may be briefly considered: (1) infection, (2) atrophy of the transplant and (3) death of the transplant.

It is not within the scope of this work to stress fully the importance of rigid preparation of the skin and a strict aseptic technic. In a personal communication from a well known surgeon who has had vast experience in the living suture repair of hernia it was stated that the percentage of infections associated with such repair was higher than in similar cases in which other suture material was used.

If the technic involves two incisions and the operation is unduly prolonged, the liability of infection is increased. The number of assistants required is usually greater, which may be regarded as another possible source of infection. Until the operating teams have performed a number of these operations, they will not work with the same coordination as when they are doing more or less routine work.

Atrophy of the transplant should be considered as a result of factors which so interfere with the process of adaptation that portions of the transplant are no longer of physiologic value. Thus the process of repair ceases, and the process of involution begins. The portions which are no longer of physiologic value will tend to be extruded. In my opinion this accounts for the serous discharge noted by many surgeons. If the process of involution is not sufficient to take care of such tissue adequately the entire transplant may die and be extruded. It should be mentioned, however, that the fibroplasia which has formed around the transplant in certain cases will be of sufficient strength to give a satisfactory result eventually. The surgeon, therefore, should not be in any haste to remove a transplant at the first sign of infection, but should rather give nature every chance to make a satisfactory repair. The process of repair will in many cases be more effective than surgical intervention in an infected field.

On what would a technic be based which would avoid the common causes of failure and at the same time incorporate the salient features of the physical properties here portrayed?

TRAUMA AND ATRAUMATIC TECHNIC

The graphic presentation of the effect of trauma (fig. 9) on fibrous tissue shows the rôle that trauma plays in weakening these tissues. The atraumatic technic of Bunnell deserves special attention.

If prepared sutures are used, trauma occurs only in the tissues in which such sutures are embedded. In transplantation of fibrous tissue, however, trauma may result in injury to the transplant, to tissues from which it is removed and to the host tissue. The technic,[34] therefore, should minimize the amount of trauma in each of these three fields.

34. Gratz, C. M.: Use of Fasciae in Reconstructive Surgery, Ann. Surg. **99**:241-245, 1934.

Incision of the skin and superficial tissues should, if possible, parallel the direction of the fibers of the transplant. Adipose tissue should be removed by sharp dissection rather than by blunt dissection or gauze. The transplant should be cut in the exact direction of its fibers and should be removed by sharp dissection to minimize trauma. The various types of fascial strippers now used may often unnecessarily traumatize the transplant. Some surgeons tear the transplant instead of dissecting it cleanly. This procedure should be condemned.

After the transplant has been removed, it should be kept in gauze moistened with saline or Ringer's solution, and no effort should be made to test its strength, as this may cause intrinsic changes. Unnecessary trauma is caused to the tissue around the transplant by inadequate incisions and excessive traction. The practice of allowing the junior members of the operating team to remove the transplant should be avoided.

It is frequently difficult to place the transplant satisfactorily in the host tissue. This is particularly the case when it is placed in rather remote osseous positions. Special instruments [35] have been devised by me for reducing the amount of trauma in inserting these sutures. Certain parts of the transplant will necessarily be traumatized, especially where clamps and needles are applied. This can be lessened by fastening the instruments only once and by not changing their fixed positions. When the sutures have been fastened in place, the traumatized areas should be removed. Since this minor point has been incorporated in the technic, serous discharge has been materially lessened.

TECHNIC TO REDUCE SHEAR PHENOMENA

This discussion will be limited to the transplantation of living suture, but all surgical procedures should be devised so as to reduce shear phenomena to a minimum.

Cutting fibrous tissues transversely necessarily causes more shear when these tissues heal than when such incisions are made parallel to the direction of the fibers. If the physiologic stress after transplantation is borne in part by the transplant and in part by the prepared sutures, the prepared sutures will necessarily produce shear. The entire postoperative stress should be borne by the transplant itself, and the fibers of the transplant should be parallel to the direction of such forces.

Practically this has been found to be easily accomplished by tying the living sutures in a square knot, preventing its slipping by small absorbable sutures, and then fastening both sides of the knot securely to fibrous tissues surrounding it. When stress is applied, the living

35. Gratz, C. M.: New Instruments for Living Sutures, Am. J. Surg. **13**:81-82, 1931.

sutures alone carry it. If large sutures are used the physiologic stresses will rarely all be evenly applied, hence a shear phenomenon will result. This can be markedly minimized by using several small sutures rather than one or two large ones. Any technic involving rolling the suture on itself or twisting it will cause shear.

In the absence of any definite determinations of tension, one should strive to place these sutures under a tension similar to that found in normal tissues. This technic will permit the suture to bear a normal amount of stress and will also permit it to resume its normal elasticity rapidly. The strength of internal fixation is thereby increased and the period of convalescence is accordingly diminished.

COMMENT

The clinical applications of these findings to autogenous transplantation have been indicated. In the words of Hawley,[9] the research work done has been clinically applied to explain "why the transplantation of mesoblastic tissue is successful in some instances and a failure in others." In addition, the clinical application of studies of shear phenomena explains why "those cut on the shear and those cut precisely in the axis of the long fibers look alike, but the former are practically useless for the biological purpose." The salient features of a technic applying these principles have been referred to and have been shown by moving pictures. Reference has been made to the various clinical procedures that have been published over a period of many years coordinating the clinical application of the principles enunciated. A sufficiently large clinical follow-up study has shown that these principles are physiologically sound.

The unpublished work of Prentiss, of Iowa State University, and the clinical application of his work by Milgram [36] to the surgical treatment of suppuration in the fascial spaces of the thigh are outstanding contributions to fascial surgery. The recent book of Singer on the anatomy of fasciae supplies a long felt need. No work on fascial surgery would be complete without due reference to the splendid research and clinical work of Koontz [37] in his use of prepared fasciae as transplants.

The fasciae of animals are functionally designed for the transmission of stress and strain and hence should be more suitable for suture material than catgut, the primary function of which is digestion. When various problems in preparing, sterilizing and placing prepared fascial

36. Milgram, J. E.: Surgery of Suppuration in the Fascial Spaces of the Thigh, J. A. M. A. **98**:117-123 (Jan. 9) 1932.

37. Koontz, A. R.: Muscle and Fascia Suture with Relation to Hernia Repair, Surg., Gynec. & Obst. **42**:222-227, 1926.

sutures have been completed, such sutures should have a large field of usefulness. It may, however, be in order to suggest that when the entire body is available for the removing of sutures, the various tendons and the fasciae of the back might prove more suitable than fascia lata. The present ox fascia lata commercially supplied could be readily improved by cutting the suture along the direction of their fibers and thus reducing shearing stress. While it is believed that autogenous fibrous tissues are theoretically the ideal suture material it is realized and hoped that their field of usefulness will always be limited to selected cases, whereas prepared fibrous sutures have theoretically a much larger field. The similarity between the biomechanical properties of tendons and fasciae has been shown throughout this entire work. This was confirmed by histologic studies and the findings correlated with the clinical application. The mesothelial covering of the fascial planes requires the development of a physiologic technic for operations on fasciae paralleling the physiologic technic of Mayer,[21] which he developed for operations on tendons. Linking the studies, however, with functional anatomy, operations on the fasciae may be of even greater importance in relation to pain and limitation of motion than operations on the tendons. The fact that the nerves, blood vessels and lymphatics traverse the fascial spaces and are in intimate contact with the mesothelial covering of these spaces makes them of the greatest surgical importance.

With these physiologic conceptions applied to operation on the fasciae, it is of interest to study operative procedures developed for the relief of symptoms in pain low in the back and sciatica.

Percy Roberts did a large number of cutting operations on the fasciae many years ago, though he did not publish the results of his work. Heyman [38] has done a similar type of operation, but it was the work of Ober [39] that has focused the attention of the surgical world on the possible rôle of the soft tissue in the syndrome of sciatic pain low in the back. Ober's [39] procedure, the dividing of the tensor fascia lata, has been widely employed by clinicians of the highest standing, and all have reported a goodly percentage of favorable results from this procedure. Nevertheless, the rationale of the operation with relation to the etiology of the pain has never been sufficiently clarified.

Manipulations of various sorts, but all fundamentally aimed at relief of pain, whether on the lumbosacral or the sacro-iliac joint, and the more recent operations on the soft tissue have all been credited with

38. Heyman, C. H.: Thoughts on the Relief of Sciatic Pain, J. Bone & Joint Surg. **16**:889 (Oct.) 1934.

39. Ober, Frank R.: The Role of the Iliotibial Band and Fascia Lata as a Factor in the Causation of Low Back Disabilities and Sciatica, J. Bone & Joint Surg. **18**:105-110, 1936.

a high percentage of good results. All these procedures, however, have one common factor; viz., the fibrous tissues are either stretched or divided in the course of treatment. If I may be permitted to speculate a bit, it may be deduced from the intimate anatomic relation which the fascial planes bear to the nerves that the relief of pain following these procedures may have been the result of the elimination of tensions on the nerve trunks lying in these tissues, produced by adhesions of the mesothelial covering of the fascial planes at points where there should be motion. Certain patients after manipulation have aggravation of the symptoms rather than relief. It is conceivable that in those patients who have been relieved the fascial adhesions to the nerve were divided by the manipulative forces, whereas in the cases in which the results were unsuccessful the adhesions did not give way but instead injured the nerves or the blood vessels when put on the stretch during the treatment.

Albee's [40] work on myofascitis, particularly the toxic involvement of these tissues, would also be confirmed not only by the histology but by the variations in the fascial planes noted by roentgenographic studies. The limitation of straight leg raising noted by him would probably be explained by toxic conditions in the fasciae with resulting fascial adhesions and contractures.

The present work with pneumofasciagrams has not solved the problem of pain low in the back, but the correlation of the entire work may be of aid in localizing the pathologic process in these cases. The therapeutic action of treatment of the fascial spaces alone is of decided clinical interest, but an adequate follow-up is necessary before conclusions can be drawn, and the utmost conservatism is being used.

This work has been developed, and the results have been of interest to many groups other than surgeons. The members of the department of pharmacology at Columbia University were particularly interested in the establishment of normal biomechanical determinations in anticipation of comparing these with similar studies in cases in which there was a disturbance of calcium metabolism. The research workers from the Bell Laboratories were also hopeful of using the normal determinations of fasciae as an aid in the study of changes of the fibrous tissues in the human ear. Plans for biomechanical studies of pulmonary adhesions have been made by clinicians studying tuberculosis. Members of the engineering and architectural professions have cooperated throughout and have been interested not only in the remarkable physical properties of the fibers of the fascial planes but also in the coordination of soft tissue movement which takes place through the fascial planes. Roentgenologists have aided in developing the technic for visualizing the fascial planes, using air as a contrast medium.

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40. Albee, Fred H.: Myo-Fascitis, Am. J. Surg. **23**:70-78, 1934.

SUMMARY

Certain physiologic properties of the fibrous tissues from a cross-section of mammalians are presented in engineering units of tensile strength and elasticity. Determinations of the proportional limit of these tissues are presented and the elasticity is measured in terms of Young's modulus. The proportional limit of biologic material is regarded as a measure of the physiologic range of elasticity and probably indicates the dividing line between stress which causes no permanent damage to fibrous tissues and stress which causes intrinsic changes and permanent impairment of function.

The similarity between species makes such determinations pertinent to man; the similarity between tendons and fasciae makes a large proportion of the research and clinical work on tendons pertinent to operations involving the fasciae. The consistency of the results of all determinations on normal adults probably indicates that the variation in weight in the individual animals is compensated for by the variation in size in the individual structures.

The studies of fibrous tissues herewith presented after normal growth and the research and clinical work herewith reviewed in relation to fibroplasia after surgical repair and transplantation show definite adaptations of form to function.

Shearing stress and trauma markedly diminish the physical properties studied, and their effect is graphically portrayed. These findings are clinically applied to devise a physiologic technic of fascial transplantation. The facts given permit the presentation of definite principles to guide one in the selection of cases and the selection of tissues suitable for fascial transplantation.

Brief reference is made to other fields in which these findings are of value. Particular reference is made to the rôle of the fascial planes in the mechanics of the soft tissues of the locomotor apparatus. The functional mechanics of the soft structures are considered in relation to the rôle of fascial adhesions in pain low in the back. Brief reference is made to the normal mesothelial covering of the fasciae and changes in these tissues in pain low in the back and arthritis. It is believed that chronic infective processes may be as closely associated with the fascial spaces as Kanavel has shown acute infections to be.

Dr. S. N. Blackberg, of the Department of Pharmacology of Columbia University; Prof. G. B. Karelitz, of the Department of Mechanical Engineering of Columbia University, and R. L. Wegel, of the Bell Laboratories, checked the work reported here during preparation and carefully reviewed it.

SIGNIFICANCE OF THE OBSTRUCTIVE FACTOR IN THE GENESIS OF ACUTE APPENDICITIS

AN EXPERIMENTAL STUDY

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AND
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MINNEAPOLIS

The significant rôle of the vermiform appendix in the causation of perityphilitic suppuration was established by Fitz,[1] of Boston, in 1886. This was almost fifty years ago, and in the intervening years, thanks to the fruitful labors of Pasteur and Lister, surgery has broadened in its scope from a science concerned primarily with the dressing of wounds to one holding an important position in the treatment of disease. Knowledge concerning the recognition of the clinical picture of appendicitis and the surgical technicalities involved in its removal have grown apace, but information concerning the nature of the origin of appendicitis remains almost as obscure as when Fitz made his prophetic pronouncement.

Appendicitis continues to prove fatal, and if one considers actuarial tabulations, the mortality is increasing. In the last twenty-five years[2] there has been an increase of 30 per cent. Whether this is apparent or real is not yet wholly evident, but it is obvious that the accomplishment of the surgeon in dealing with acute appendicitis has not kept stride with his potential capacity of coping with the problem. The supreme misfortune which can befall a man, said Leonardo de Vinci, is that theory outstrips performance.

How this record can be best improved is not immediately clear. A common human failing of overhopeful optimism and too frequent practice of the policy of "wait and see" by both the patient and the

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1. Fitz, R. H.: Perforating Inflammation of the Vermiform Appendix with Especial Reference to Its Early Diagnosis and Treatment, Am. J. M. Sc. **92**:321, 1886.

2. Hoffman, F. L.: Appendicitis Record of 1934, Spectator (Life Ed.) **135**: 6, 1935. Wilkie, D. P. D.: Observations on Mortality in Acute Appendicitis, Brit. M. J. **1**:253, 1931.

physician probably account in a large measure for the unwarranted number of deaths from a malady which if treated intelligently and opportunely would command no great hazard to life. The confused present state of medical opinion concerning the causative factors of appendicitis undoubtedly contributes in no small measure to this somewhat humiliating achievement with the problem of appendicitis. Whereas a disease process may frequently be treated fairly successfully in an empirical fashion, an adequate appraisal of the nature of the disease invariably, in the better understanding, lends a tremendous impetus to the correction of defects in its management.

PRESENT CONCEPTS OF THE ORIGIN OF APPENDICITIS

The chaotic condition of knowledge with reference to the etiology of appendicitis may readily be discovered by perusal of a few of the numerous papers in the literature which profess to bring enlightenment into this disordered state. One gains the impression from studies made with reference to the geographic distribution of appendicitis [3] that in the main it is a disease of civilization and culture, in which diet and lack of physical activity are the chief determinants. How much credence one may with confidence give these general observations is a pertinent query. The physician learns from experience that as the vagaries of a disease process are more familiar, the condition seems to be encountered more often. There is, moreover, no reliable information to indicate that the disease actually is more frequent in countries where it may be properly identified than it was before it was recognized.

In the diet, the following have been alleged to be of some importance in predisposing to the occurrence of appendicitis: [4] food preservatives, enamel ware employed in cooking, the extensive eating of frozen and preserved meat, bananas, increased consumption of sugar, iron from the iron rollers employed to grind grains into flour and cereals and an inadequate amount of cellulose. These and a large number of other dietary items have been held accountable for the frequency of appendicitis among civilized people.

Among exciting causes, infection and obstruction are commonly acknowledged as being likely etiologic agencies. Those who admit the obstructive element contend that it probably accounts for only a minority of the cases. The factor of infection, then, is generally conceded as playing the dominant rôle in the production of acute appendicitis. In what manner the infection reaches the appendix, even among those

3. Murray, R. W.: The Geographical Distribution of Appendicitis, Lancet **2**:2227, 1914.

4. Short, A. R.: The Causation of Appendicitis, Brit. J. Surg. **8**:171, 1920.

who maintain that appendicitis is solely a bacterial disease, is not a matter of agreement. Adrian [5] and Kretz [6] hold that the disease is blood borne, usually from an infection of the throat and tonsils. Poynton and Paine [7] and Rosenow [8] by inoculation of animals have brought forth experimental data to support this belief, and such an opinion is wholeheartedly shared by a large number of surgeons and practitioners. Aschoff,[9] who gave the problem considerable thoughtful and critical study, maintained, on the contrary, that the infection arises in the majority of instances from within the bowel. In a recent monograph on the subject,[9c] he set forth the opinion that appendicitis is probably a specific bacterial disease, like gonorrhea; that the causative agent, an enterococcus, more specifically a type of streptococcus, corresponding to Gundel's [10] enterococcus type B, which Aschoff described as a gram-positive diplococcus, normally resides in the distal third of the appendix and under proper conditions becomes pathogenic and gives rise to the pathologic picture of appendical suppuration.

In normal appendixes, Aschoff has found a flora of organisms which is not unlike that of the cecum, consisting of streptococci, colon bacilli and gram-positive rods in the proximal two thirds of the appendix in from 62 to 70 per cent of instances. In the distal third, however, diplococci are found as the sole or predominant organism in the majority of instances. In acute suppuration of the appendix, Aschoff has found diplococci in pure culture in 65 per cent of instances, and when the allied enterococci and nonhemolytic streptococci are included, these organisms are accountable for more than 70 per cent of instances of

5. Adrian, C.: Die Appendicitis als Folge einer Allgemeinerkrankung—Klinischer und Experimentelles, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **7**:407, 1901.

6. Kretz, R.: Untersuchungen über die Aetiologie der Appendicitis, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **17**:1, 1907.

7. Poynton, F. J., and Paine, A.: Experimental Appendicitis by General Blood Stream Infection, Tr. M. Soc. London **35**:243, 1912; Lancet **2**:439, 1912.

8. Rosenow, E. C.: The Bacteriology of Appendicitis and Its Production by Intravenous Injection of Streptococci and Colon Bacilli, J. Infect. Dis. **16**:240, 1915; Focal Infection and Elective Localization of Bacteria in Appendicitis, Ulcer of the Stomach, Cholecystitis, and Pancreatitis, Surg., Gynec. & Obst. **33**:19, 1921.

9. Aschoff, L.: (*a*) Ueber die Bedeutung des Kotsteines in der Aetiologie der Epityphlitis, Med. Klin. **24**:587, 1905; (*b*) Die Wurmfortsatzentzündung, Jena, Gustav Fischer, 1908; (*c*) Appendicitis: Its Etiology and Pathogenesis, London, Constable & Co., Ltd., 1931.

10. Gundel, M.: Ueber die "Erregerfrage" bei der Appendicitis im post-appendicularen Peritonitis, Arch. f. klin. Chir. **172**:597, 1933. Gundel, M.; Pagel, W., and Sussbrich, F.: Untersuchungen zur Aetiologie der Appendicitis und post-appendiculären Peritonitis, Beitr. z. path. Anat. u. z. allg. Path. **91**:399, 1933.

acute appendicitis. Moreover, Aschoff [11] stated that these organisms are the likely pathogenic agents in probably 100 per cent of the cases.

A large number of investigators share in part the view expressed by Aschoff, i. e., that inflammation of the appendix arises locally from the bowel and is not blood borne. The greater number of these, however, believe that a number of organisms may cause suppuration in the appendix and that the infection is brought to the appendix by way of the proximal portion of the intestinal canal. Hilgermann and Pohl [12] find in suppurative appendicitis the same organisms, in the main, as may be found on culture of material from the throat in tonsillitis, viz., pneumococci, streptococci, diphtheroid bacilli and Vincent's organisms. They expressed the belief that these organisms are swallowed, find their way into the appendix and set up in the submucosal lymphoid tissue the same type of inflammation as they cause in the tonsil. Warren,[13] in a combined histologic and bacteriologic study, concluded, on what appears to be good evidence, that a variety of organisms may give rise to suppurative appendicitis.

EXPERIMENTAL INVESTIGATION

PURPOSE

The thought which is frequently in the surgeon's mind concerning the appendix is that it is essentially a long, narrow diverticulum of the cecum with an arrangement unfavorable for ready and complete evacuation of its content. Specific infection in the alimentary canal is so unusual as to suggest that the anatomic plan of the vermiform appendix may be largely responsible for the frequency with which appendicitis occurs in man. With this consideration as a premise, we have tried to evaluate the significance of the obstructive factor in the genesis of appendicitis by experiments on animals and by careful observation of the frequency with which obstructive phenomena are noted in the spontaneous occurrence of the disease in man.

CHOICE OF ANIMAL AND ANATOMIC CONSIDERATIONS

The vermiform appendix of man represents the true apex of the cecum. One of the characteristics of the cecal apex which the human appendix exhibits in liberal measure after the first few weeks of life

11. Aschoff,[9c] pp. 68 and 69.

12. Hilgermann, R., and Pohl, W.: Beitrag zur Aetiologie und Serum Therapie der foudroyanter Appendicitis auf Grund der Beobachtungen bei 300 Fällen im Kreise Deutsch-Krone, Arch. f. klin. Chir. **154**:248, 1929.

13. Warren, Shields: Etiology of Appendicitis, Am. J. Path. **1**:241, 1925.

is a large amount of lymphoid tissue.[14] Not many mammals besides man possess a true vermiform appendix. Of the common laboratory animals, the rabbit is the only one which does. Its appendix is a real lymph gland, in which the chief distinguishing feature is the extremely abundant lymphoid tissue. The wombat, the lemur and the higher anthrapoid apes possess a true vermiform appendix. The spontaneous occurrence of appendicitis in the chimpanzee has been recorded. Weinberg found evidence of acute suppurative appendicitis in ten of sixty-one chimpanzees dying in captivity. He has also reported its occurrence in a gorilla and accompanied his report by well supported proof in appended illustrations. Murray stated that Plummer observed the spontaneous occurrence of appendicitis in three higher apes (one chimpanzee

Fig. 1.—Photomicrograph of a normal dog's cecal appendage.

and two gibbons) at the London Zoo. He also observed inflammation of the cecal apex in fifteen wild animals of various kinds dying in captivity. Dr. Hamerton, pathologist of the Zoological Society of London, recently wrote us that only two instances of appendicitis have been observed there in the subhuman primate family in the last twenty years. Both occurred in gibbons. The director of the Zoological Gardens in Berlin wrote us that a single instance of appendical abscess had been observed there, in a 10 year old gorilla.

In this study the dog, in which the cecum is an appendage to the colon, was largely used. A lesser number of experiments were also done on rabbits. True, the dog does not have a true vermiform appen-

14. Berry, R. J. A., and Lack, L. A. H.: The Vermiform Appendix of Man and the Structural Changes Therein Coincident with Age, J. Anat. & Physiol. **40**: 247, 1905.

dix, but as the appendix and the cecal apex are comparable structures, it was felt that no apology need be offered in employing the cecal appendage of the dog. In this study, extending over two years, one hundred and thirty-nine experiments were done on dogs and ten on rabbits (fig. 1).

MODE OF STUDY

The greater portion of this experimental inquiry concerns itself with the factors of obstruction and infection. In addition, a lesser number of experiments have been done in which the blood supply to the appendix was interfered with, and finally a miscellaneous group of somewhat unrelated experiments were done with a view to a better interpretation of the preceding experiments.

The essential approaches to the problem employed in this experimental inquiry are as follows: (1) establishment of obstruction—complete and incomplete—to the cecal apex with and without washing of the lumen; the employment of peritoneal exudates; the maintenance of sustained intraluminal pressure, and the isolation of the cecal appendage as a closed loop; (2) determination of the rôle of infection with relation to the absence of obstruction, the presence of partial and complete obstruction, the significance of the specificity of organisms and embolic systemic infection; (3) interference with the circulation of the cecal apex; (4) traumatization of the wall; transplantation of the vascularized cecal apex to other segments of the intestinal canal; the injection of phenol into the lumen and of exudate, organisms and melted paraffin into the wall of the cecal apex.

All operations were done under the usual aseptic precautions. No animal was starved longer than twelve hours before operation. Pentobarbital sodium (35 mg. per kilogram of body weight) was given intraperitoneally for anesthesia. In the experiments in which continuous increased intraluminal pressure was maintained over a considerable period, this anesthesia was supplemented by the use of morphine.

The cecal appendage was excised under sterile technic at varying intervals of time after the performance of the procedures outlined. In the majority of instances the results of the examination of tissues here reported concerned living dogs. Animals dead for several hours at the time of postmortem examination were discarded from consideration. The excised tissues were fixed in a diluted solution of formaldehyde U. S. P. (1:10) for twenty-four hours, after which representative blocks were cut. These blocks were embedded in paraffin and stained with hematoxylin and eosin for histologic examination, and in the greater number of instances the Gram-Weigert stain was used as well for purposes of studying the bacteria. In the majority of cases smears and cultures were made from the lumen and wall of the cecal apex for identification of the bacteria present.

CRITERIA OF DIAGNOSIS

In each instance the gross features were carefully noted. Hemorrhage, gangrene, perforation, thickening and thinning of the wall and suppuration represent the variety of macroscopic pathologic changes noted. A diagnosis of acute inflammatory change was made only in cases in which microscopic evidence of edema, hemorrhage and leukocytic infiltration of the wall of the bowel, predominantly of the poly-

morphonuclear variety, were demonstrable. Such changes limited to the serosa were considered the result of operative trauma. Mild acute appendicitis was diagnosed in the presence of minimal diffuse reaction; moderately severe acute appendicitis, in the presence of moderate reaction, and gangrenous appendicitis, in the presence of severe hemorrhage with evidence of tissue necrosis (fig. 2).

Fig. 2.—Photomicrograph indicating the marked serosal edema and leukocytic infiltration characteristic of the sections in the experimental series on which a diagnosis of acute appendicitis was made. The section was taken from dog 130 after maintenance of 8 cm. of constant water pressure for six hours.

RESULTS OF EXPERIMENTS

OBSTRUCTION

COMPLETE OBSTRUCTION.—*Complete Obstruction of the Lumen of the Cecal Appendage by a Ligature at the Base.*—There were eight dogs in this series, in which complete obstruction of the lumen of the cecal appendage was produced by ligature at the base with heavy linen thread. In three dogs the cecal appendage was excised after six hours of obstruction; in three, after eighteen hours, and in two, after twenty-four hours. After six hours of obstruction one cecal appendage was normal, one was definitely acutely inflamed and four were gangrenous. After eighteen hours, one was normal, and the other two were gangrenous. After twenty-four hours one showed definite evidence of acute inflammation, while the other was gangrenous. In each case in which the appendix was normal it was found to be

firmly contracted down, whereas the acutely inflamed and gangrenous specimens were tensely distended with a hemorrhagic fluid. Smears of this fluid from each cecal appendage usually showed an abundance of leukocytes and a wide variety of organisms, including B. coli, B. Welchii, and gram-positive and gram-negative streptococci. In one instance many gram-positive diplococci were seen within the leukocytes (table 1).

TABLE 1.—*Result of Complete Obstruction of the Cecal Appendage by Ligature*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
1	6	Much bloody peritoneal fluid; cecal appendage gangrenous and tensely distended with fluid	Gram-positive rods, diplococci, diplobacilli and streptococci; very sparse gram-negative diplococci	Acute gangrenous appendicitis
2	6	Much bloody peritoneal fluid; cecal appendage moderately congested	.....	Normal
41	6	Moderate peritoneal fluid; cecal appendage congested and distended	Gram-positive diplococci; gram-negative rods and diplococci	Early acute appendicitis
5	18	Much foul peritoneal fluid; cecal appendage gangrenous and tensely distended with fluid	Gram-positive streptococci, rods and large bacilli	Acute gangrenous appendicitis
6	18	No peritoneal fluid; cecal appendage grossly normal	.....	Normal
42	18	Moderate peritoneal fluid; cecal appendage gangrenous in two areas and tense; contents foul and bloody	Phagocytosis of gram-positive diplococci; gram-positive rods, diplobacilli, streptococci and diplococci; gram-negative bacilli, streptococci and diplococci	Acute gangrenous appendicitis
7	24	Cecal appendage gangrenous and tensely distended with fluid	Many leukocytes; sparse gram-negative streptococci and diplococci	Acute gangrenous appendicitis
8	24	Moderate bloody peritoneal fluid; cecal appendage congested	Gram-positive diplococci	Acute appendicitis

TABLE 2.—*Result of Complete Obstruction of the Cecal Appendage and Introduction of Virulent Peritoneal Exudate in the Lumen*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
27	24	Much foul bloody peritoneal fluid; cecal appendage completely gangrenous; many perforations	Phagocytosis of gram-positive diplococci; gram-positive rods, diplococci and streptococci, gram-negative rods, diplococci, streptococci	Acute gangrenous appendicitis
28	24	Cecal appendage grossly normal except for moderate edema	.....	Acute appendicitis

Ligature of the Cecal Appendage at the Base and Introduction of Virulent Peritoneal Exudate into the Lumen.—In two dogs a small gelatin capsule containing virulent peritoneal exudate from a dog dying of peritonitis from rupture of an obstructed cecal appendage (cultures showed fecal type of flora) was introduced into the cecum and maneuvered into the cecal apex, which was then obstructed at its base for twenty-four hours. In both instances the cecal appendage showed acute changes, one being gangrenous. Phagocytosis of gram-positive diplococci was again noted in the fluid. The changes in these tissues were more severe than in the previous experiments, and the gangrenous cecal appendage exhibited multiple perforations (table 2).

Ligature of the Cecal Appendage at the Base and Injection of Melted Paraffin into the Wall of the Cecum Distal to the Ligature.—In two dogs melted paraffin was injected into the wall just beyond the obstructing ligature. One dog died of generalized peritonitis in twenty-four hours, from pressure necrosis and perforation at the site of injection. In the other the cecal appendage was excised in seventy-two hours; necrosis was present in the area in which the injection was made, with milder acute changes demonstrable elsewhere (table 3).

Ligature of the Cecal Appendage at the Base After Washing the Lumen.—This group is composed of three dogs; the cecal appendages were thoroughly washed out with 100 cc. of tap water, a large glass syringe and fine needle being used, followed by ligature at the base. In two dogs the cecal appendage was removed

TABLE 3.—*Result of Complete Obstruction of the Cecal Appendage and Submucosal Injection of Melted Paraffin*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
31	72	Generalized peritonitis and abscesses; base of cecal appendage necrotic; pus in lumen	.....	Acute appendicitis
32	24	Died of peritonitis due to gas formation; cecal appendage showed peritonitis	Gram-positive large bacilli, diplococci and streptococci rare gram-negative streptococci and bacilli	Serositis

TABLE 4.—*Result of Complete Obstruction of Empty, Washed Cecal Appendage*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
15	96	No fluid; cecal appendage contracted and grossly normal; omentum adherent; small inspissated fecal mass	Very sparse organisms; gram-positive diplococci, streptococci and spore-forming bacilli; rare gram-negative diplococci and streptococci	Normal
16	96	No fluid; cecal appendage contracted and grossly normal; omentum adherent; small inspissated mass in lumen	Very sparse organisms; gram-positive diplococci, streptococci and spore-forming bacilli; rare gram-negative diplococci and streptococci	Normal
53	120	Died of diffuse abscesses of lung; peritoneal cavity normal except for postmortem changes	.....	Normal

in ninety-six hours and in the other after five days. In no instance was evidence of inflammation noted in the sections; the cecal appendage in each instance was considerably contracted. It should be noted that the factor of distention was absent, although smears from the lumen showed the usual fecal organisms (table 4).

Ligature of the Cecal Appendage at the Base After Washing the Lumen; Release of the Ligature After Some Time; Placement of Feces in the Lumen; Ligature at the Base.—In three dogs the cecal appendage was washed and obstructed for five days. When the second laparotomy was performed the cecal appendages appeared grossly normal. They were then filled with fecal material and reobstructed. One animal died of pulmonary aspiration within six hours. There were petechial hemorrhages over the surface of the cecal appendage, and sections showed early acute inflammatory changes. In one dog the cecal appendage

was removed six days later and was found to be normal, but the obstructing ligature had cut through the tissues and the lumen had become reestablished. The third animal showed acute inflammation of the cecal appendage when it was removed on the seventh day, but the lumen was not distended, and the process was apparently subsiding (table 5).

INCOMPLETE OBSTRUCTION.—*Stenosis of the Appendical Lumen by Ligature of Cecal Appendage at the Base.*—In three dogs stenosis of the lumen was established for seventy-two hours. In one the cecal appendage showed mild acute changes,

TABLE 5.—*Result of Complete Obstruction of Empty Washed Cecal Appendage, Introduction of Feces After Five Days and Reobstruction*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
33	168	Many adhesions and small abscesses; cecal appendage contracted and walled off; small inspissated mass in lumen	Gram-positive diplococci; gram-negative rods, diplococci and streptococci	Acute appendicitis
34	6	Died of aspiration; cecal appendage distended, walls congested and covered by petechiae	.....	Early acute appendicitis
52	144	Cecal appendage grossly normal; ligature had cut through and lumen partially reestablished; marked stenosis	Gram-positive diplococci; gram-negative rods and diplococci	Normal

TABLE 6.—*Result of Stenosis of the Cecal Appendage by Ligature*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
9	72	No fluid; cecal appendage grossly normal; slight edema	.....	Early acute appendicitis
10	72	No fluid; grossly normal; fecaliths in lumen	.....	Normal
43	72	Moderate peritoneal fluid; cecal appendage edematous and congested; fecaliths in lumen	Gram-positive rods and diplococci; gram-negative rods, diplococci and streptococci	Normal

TABLE 7.—*Result of Stenosis of the Cecal Appendage Around a Glass Cannula*

Dog No.	Hr.	Gross Description	Diagnosis
11	24	Tube forced through stenosed area and found in rectum; cecal appendage showed moderate congestion	Acute appendicitis
12	24	Cecal appendage edematous and hemorrhagic; fecaliths in lumen	Acute appendicitis

while in the others there was no evidence of inflammation. In all three instances the lumen contained a very inspissated fecal mass, indicating some mechanical dysfunction (table 6).

Placement of a Flanged Tube With a Small Lumen in the Cecal Appendage.—In two dogs stenosis was established around a flanged glass tube introduced through the cecum, with its large end in the apex. The cecal appendage, which was removed in twenty-four hours, exhibited acute inflammation, but it was observed that feces had completely plugged the glass tube, so that in reality a complete obstruction had been present (table 7).

Stenosis and the Introduction of a Foreign Body into the Lumen.—This group comprises eight dogs in which a glass marble was introduced into the cecal apex through the proximal portion of the bowel. The lumen was then stenosed sufficiently by ligature to prevent the escape of the foreign body. The cecal appendages were removed after six, eighteen, twenty-four, fifty-two and seventy-two hours. One of the twenty-four and one of the seventy-two hour specimens showed acute changes and in both of these the marble was tightly pressed against the stenosing ligature by muscular spasm so that a complete obstruction was present. In the other specimens, which were normal, the marbles were found lying free within the lumen of the appendage (table 8).

TABLE 8.—*Result of Stenosis of the Cecal Appendage and Introduction of a Foreign Body in the Lumen*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
13	6	Moderate peritoneal fluid; cecal appendage grossly normal; had contracted and marble was tight against suture	Gram-positive diplococci, diplobacilli and streptococci; gram-negative cocci, diplococci, bacilli and streptococci	Serositis
114	6	Cecal appendage relaxed and normal	.....	Normal
17	18	Cecal appendage grossly normal; marble tight against ligature; fecaliths in lumen	.....	Serositis
18	18	Moderate peritoneal fluid; cecal appendage relaxed and normal	.....	Normal
19	24	Cecal appendage grossly normal; marble tight against ligature	.....	Early acute appendicitis
20	24	Moderate bloody peritoneal fluid; cecal appendage edematous and showed petechiae; marble tight against ligature; fecaliths in lumen	.....	Serositis
26	52	Generalized gas bacillus infection; postmortem changes	.....	Postmortem necrosis
44	72	Cecal appendage contracted, edematous and showed petechiae; fecaliths	Gram-positive diplococci; gram-negative rods and diplococci	Acute appendicitis

Stenosis and the Introduction of Virulent Peritoneal Exudate into the Lumen.—In four dogs a capsule of virulent peritoneal exudate from a dog dying of peritonitis was introduced into the cecal appendage through the proximal portion of the bowel. Stenosis of the base of the appendage was then produced by means of a ligature. In two animals the appendage was removed after eighteen hours, and in the remaining two, after twenty-four hours. All exhibited a rather severe inflammatory reaction. In some of these edema of the mucosa had produced a complete obstruction (table 9).

Stenosis and the Introduction of a Foreign Body and Virulent Exudate into the Lumen.—In this group nine dogs were used. A capsule of virulent peritoneal exudate was introduced into the appendix through the cecum, and this was followed by the introduction of a glass marble. Stenosis of the base of the cecal appendage was then produced, the marble being proximal to the capsule. In these animals the cecal appendage was removed after eighteen, twenty-four and ninety-six hours and

after seven and nine days. In six instances definite acute inflammation was demonstrable. The animal in which the cecal appendage was removed after nine days was very ill, with nausea and vomiting for four days, and then spontaneously passed the marble by rectum. He showed marked improvement, and his reactions

TABLE 9.—*Result of Stenosis of the Cecal Appendage and Introduction of Virulent Peritoneal Exudate in the Lumen*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
21	18	Moderate peritoneal fluid; cecal appendage edematous; petechiae	Gram-positive diplococci and streptococci; gram-negative rods, diplococci and streptococci	Acute appendicitis
22	18	Edema of cecal appendage; petechiae	Gram-positive diplococci and streptococci; gram-negative rods, diplococci and streptococci	Acute appendicitis
23	24	No fluid; cecal appendage grossly normal but for some edema	.....	Acute appendicitis
23.5	24	Moderate bloody peritoneal fluid; cecal appendage hemorrhagic	.....	Acute appendicitis

TABLE 10.—*Result of Stenosis of the Cecal Appendage and Introduction of a Foreign Body and Virulent Peritoneal Exudate into the Lumen*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
3	18	Moderate peritoneal fluid; edema and petechiae; fecaliths in lumen	.....	Acute appendicitis
4	18	Moderate peritoneal fluid; edema and petechiae	.....	Acute appendicitis
24	24	Some bloody peritoneal fluid; edema and petechiae; friable	.....	Acute appendicitis
25	24	Moderate peritoneal fluid; some edema of cecal appendage	Gram-positive diplococci, streptococci and rods	Normal
51	24	Moderate peritoneal fluid; edema and petechiae; fecaliths	Gram-positive diplococci and rods; gram-negative rods and streptococci	Normal
39	96	Cecal appendage hemorrhagic; fecaliths	.....	Normal
45	168	Cecal appendage grossly normal	Gram-positive diplococci and rods; gram-negative diplococci, streptococci and rods	Acute appendicitis
46	168	Cecal appendage edematous; petechiae	Gram-positive diplococci, streptococci and rods; gram-negative diplococci, streptococci and rods	Acute appendicitis
40	216	Dog very ill 4 days and then passed marble; cecal appendage showed petechiae and edema; fecaliths	Gram-positive rods and diplococci; gram-negative rods and diplococci	Mild acute appendicitis

were normal by the ninth day. Examination of the specimen showed minimal acute changes, apparently in regression (table 10).

Stenosis and the Injection of Melted Paraffin Submucosally.—After stenosis of the lumen of the cecal appendage of two dogs was produced by a ligature, melted paraffin was injected into the submucosa, and the specimens were removed after

seventy-two hours. In both instances acute inflammatory changes were present, which were attributed to the hot paraffin (table 11).

MAINTENANCE OF CONSTANT INCREASED INTRALUMINAL PRESSURE.—In the foregoing experiments it was observed that in almost every instance in which an acute inflammatory reaction was induced there had been distention of the lumen by fluid. The following experiments were devised to determine what effect constant increased intraluminal pressure would have on the wall of the cecal appendage of the dog. This group is composed of eighteen dogs, and in each instance a metal cannula was introduced into the lumen of the cecal appendage at its base through an incision

TABLE 11.—*Result of Stenosis of the Cecal Appendage and Submucosal Injection of Melted Paraffin*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
29	72	Some bloody peritoneal fluid; cecal appendage hemorrhagic and bound down; edema; fecaliths	.....	Acute appendicitis
30	72	Some bloody peritoneal fluid; cecal appendage edematous and congested; pus in lumen	Gram-positive diplococci and streptococci; gram-negative rods, diplococci and streptococci	Acute appendicitis

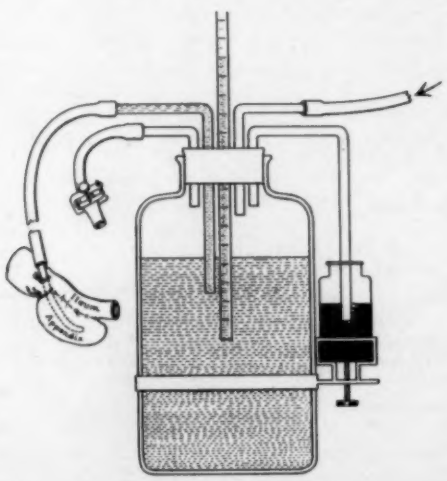

Fig. 3.—A constant pressure apparatus which can be arranged to deliver any desired air or water pressure.

made in the proximal portion of the colon. The base of the cecum was then tied tightly about the cannula, which was attached to a Perusse[15] constant pressure apparatus which could be arranged to deliver any pressure desired (fig. 3). The dogs were kept under pentobarbital sodium and morphine anesthesia during the experiments, which were carried on for six hours in nine animals and for eighteen hours continuously in the other nine. Pressures of 3, 8, 15 and 30 cm. of water and of 15 and 30 cm. of air were maintained. In one third of the dogs, the lumens

15. Perusse, G. L.: Selection of Proctoclysis Fluids, Surg., Gynec. & Obst. **54**:770, 1932.

were washed clean; in one third the fecal contents were left in the lumen, and in the other third the lumens were washed, and virulent staphylococci were introduced before the cannula was tied in place. Every specimen exhibited acute pathologic changes in the extreme, amounting to gangrene in ten of the eighteen dogs. It was found that a sustained intraluminal pressure as low as 3 cm. of water over a six

TABLE 12.—*Results of Pressure Experiments of Six Hours' Duration*

Dog No.	Pressure, Cm.	Medium	State of Preparation	Edema	Hemorrhage	Gangrene	Diagnosis
119	3	Water	Washed	Grade 1	Grade 1	None	Acute appendicitis
130	8	Water	Washed	Grade 1	Grade 1	None	Acute appendicitis
121	15	Water	Washed	None	Grade 4	Grade 1	Gangrenous appendicitis
123	8	Water	Full	Grade 1	None	None	Acute appendicitis
125	15	Water	Full	None	Grade 4	Grade 1	Gangrenous appendicitis
126	8	Water	Hemolytic staphylococci introduced	Grade 1	Grade 1	None	Acute appendicitis
128	15	Water	Hemolytic staphylococci introduced	None	Grade 3	Grade 1 (?)	Acute appendicitis
97	15	Air	Washed	Grade 1	Grade 2	None	Acute appendicitis
103	30	Air	Full	Grade 1	Grade 3	Grade 1 (?)	Acute appendicitis

TABLE 13.—*Results of Pressure Experiments of Eighteen Hours' Duration*

Dog No.	Pressure, Cm.	Medium	State of Preparation	Edema	Hemorrhage	Gangrene	Diagnosis
118	8	Water	Washed	Grade 1	Grade 1	None	Acute appendicitis
120	15	Water	Washed	None	Grade 2	None	Acute appendicitis
122	8	Water	Full	None	Grade 4	Grade 1	Gangrenous appendicitis
124	15	Water	Full	Grade 1	Grade 3	Grade 1 (?)	Acute appendicitis
127	8	Water	Hemolytic staphylococci introduced	None	Grade 4	Grade 1	Gangrenous appendicitis
129	15	Water	Hemolytic staphylococci introduced	Grade 1	Grade 3	Grade 1 (?)	Acute appendicitis
109	30	Water	Full	None	Grade 3	Grade 1 (?)	Acute appendicitis
104	30	Air	Washed	Grade 1	Grade 2	None	Acute appendicitis
114	30	Air	Full	None	Grade 3	Grade 1 (?)	Acute appendicitis

hour period produced acute inflammatory changes. In this series there appears to be no direct correlation between the content of the lumen and the severity of the reaction, the pressure apparently being the more important factor. In the nine experiments of six hours' duration, four cecal appendages showed gangrene, as compared with six in the nine experiments of eighteen hours' duration (fig. 4 and tables 12 and 13).

Isolation of the Cecal Appendage as a Closed Loop.—*Washed Lumens.*—In two dogs the cecal appendage was washed, severed from the cecum and inverted by two layers of suture. The appendage was thus converted into a short, clean closed loop. One of these was removed in forty-eight hours and the other after six weeks. The specimen removed after six weeks was much contracted, and its lumen contained a small amount of white mucoid material. Microscopic sections

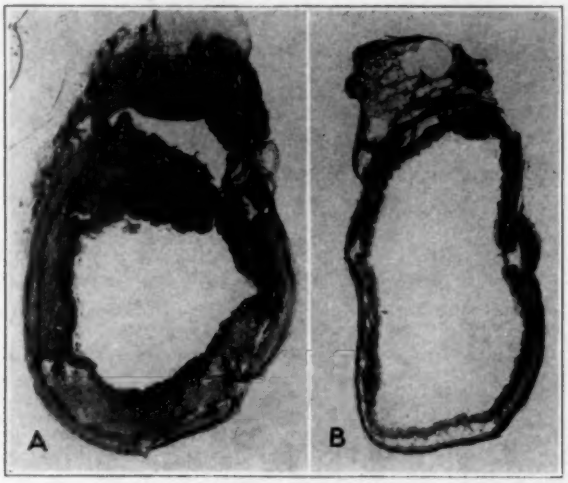

Fig. 4.—*A*, a photomicrograph showing the effect of 15 cm. of water pressure maintained for eighteen hours. *B*, a photomicrograph showing the effect of 30 cm. of water pressure maintained for eighteen hours.

Fig. 5.—Photomicrograph of a dog's cecal appendage after it had been converted into a washed closed loop for six weeks. There are no inflammatory changes; the walls are contracted and the lumen contains a mucoid material.

failed to show evidence of inflammation in the wall. A clean closed loop of descending colon about 4 inches (10 cm.) in length was made in another dog and inspected in six weeks. Here a large cyst containing mucus had developed. Four clean closed appendical loops established in the appendixes of rabbits were normal histologically after one month (fig. 5).

Lumens Full of Fecal Matter.—In four dogs closed loops of the cecal appendage were formed with the lumens full of fecal matter. In each case the loop ruptured within forty-eight hours, and the dog died of peritonitis. Microscopic sections showed gangrenous changes. A full loop of the descending colon ruptured in thirty-six hours. Two full appendical closed loops were made in rabbits. One animal died of perforation and peritonitis in thirty-six hours. The other was operated on after four weeks. Perforation of the cecal appendage with pseudocyst formation had occurred.

THE RÔLE OF INFECTION, INVOLVING THE USE OF SPECIFIC ORGANISMS

Complete Obstruction of the Lumen for Twenty-Four Hours.—In this group five dogs were used. If fecal content could be palpated through the wall of the cecum it was carefully massaged back into the colon previous to placement of the ligature. (Obstruction by ligature of such an empty though unwashed cecal appendage, it was found, was not followed by inflammatory change.) The cecal appendage was obstructed with a ligature at its base, and 5 cc. of a broth culture of one of the following virulent organisms was injected into the lumen through a fine hypodermic needle, the site of injection being the apex of the cecal appendage: (1) Pneumococcus type 3, (2) Staphylococcus aureus-haemolyticus, (3) Streptococcus haemolyticus, (4) B. Welchii and (5) B. pyocyaneus. After twenty-four hours the cecal appendage of each dog was excised. All exhibited definite evidence of acute inflammation except the one into which B. Welchii was injected. There appeared to be a definite relationship between the degree of distention by fluid and the severity of the changes.

Stenosis of the Lumen for Twenty-Four Hours.—Again five dogs were used, and the same organisms were injected into the lumens, which were simply stenosed by means previously described in this paper. Those into which staphylococci and streptococci had been introduced showed mild acute pathologic changes, and the others were normal.

Stenosis with a Foreign Body in the Lumen for Twenty-Four Hours.—In five dogs stenosis of the cecal lumens was produced with a marble in the lumen, and the same organisms were introduced. Those into which pneumococci, streptococci and B. pyocyaneus were injected showed acute changes of slightly more severe degree than those described in the previous experiment.

Injection of the Same Organisms into the Wall of the Cecal Appendage.—Five minims of a broth culture of these same organisms was injected into the wall of unobstructed cecal appendages of five dogs. Forty-eight hours later the specimens were excised. Reactions similar to those attending the injection of these organisms into other tissues were observed. The injection of staphylococci was followed by the formation of a circumscribed abscess. Pneumococci produced a less localized abscess. Streptococci gave a phlegmonous reaction, B. Welchii a hemorrhagic area and B. pyocyaneus a necrotic area surrounded by a zone of green pigmentation.

Trauma to Cecal Appendage Followed by the Intravenous Injection of Virulent Organisms.—In five dogs the cecal appendages were rather severely traumatized by rubbing them between the thumb and the forefinger, and 5 cc. of the broth culture of the aforementioned organisms was injected into a vein in the leg. The cecal appendages were removed in forty-eight hours, and the walls and contents were cultured. In each case it was felt that probably the original organism was recovered, except in the case of the dog given an injection of B. pyocyaneus. The

experiment was repeated twice, with B. pyocyaneus, but in no instance could the organism be recovered. This rather suggests that the other organisms were probably resident in the cecal appendage before the intravenous injection.

It is to be noted that whereas the injection of an exudate (mixed organisms—virulent peritoneal exudate) caused acute inflammation in 100 per cent of instances in the presence of obstruction, the injection of specific organisms was effective in only 80 per cent. In the experiments in which stenosis was produced there were acute changes in 100 per cent of the appendages in the group in which the peritoneal exudate was used, in contrast to the acute changes in 40 per cent of the appendages in the group in which the specific organisms were used. Again, in the experiments

TABLE 14.—*Summary of Results of Experiments with Specific Organisms*

Time, Hr.	Procedure	Pneumococcus Diagnosis	Staphylococcus Diagnosis	Streptococcus Diagnosis	Cl. Welchii Diagnosis	B. Pyocyaneus Diagnosis
24	Complete obstruction	Mild acute appendicitis	Gangrenous appendicitis	Mild acute appendicitis	Normal	Acute appendicitis
24	Stenosis of lumen	Normal	Mild acute appendicitis	Mild acute appendicitis	Normal	Normal
24	Stenosis and introduction of foreign body	Mild acute appendicitis	Normal	Acute appendicitis	Normal	Mild acute appendicitis
48	Injection into wall	Mild acute appendicitis	Acute appendicitis	Acute appendicitis	Mild acute appendicitis	Gangrenous appendicitis
48	Trauma to cecal appendage and intravenous introduction of organisms	Recovery of organism in blood and tissues	Recovery of organism in tissues	Recovery of organism in blood and tissues	Recovery of organism in blood and tissues	Organism not recovered in blood or tissues

TABLE 15.—*Comparison of Results with Peritoneal Exudate and Specific Organisms*

	Peritoneal Exudate		Specific Organism	
Procedure	No. of Dogs	Positive Acute Changes, Percentage	No. of Dogs	Positive Acute Changes, Percentage
Complete obstruction	2	100	5	80
Stenosis of lumen	4	100	5	40
Stenosis and introduction of foreign body	9	66	5	60

in which stenosis was produced with a foreign body in the cecal appendage, there were acute changes in 66 per cent of the appendages in the group in which the peritoneal exudate was used, as compared to the same changes in 60 per cent of the appendages in the group in which the specific organisms were used. Thus, in this small series, in no case were the specific cultures as effective in producing appendicitis as was the culture of the mixed peritoneal exudate (tables 14 and 15).

INTERFERENCE WITH THE CIRCULATION OF THE CECAL APPENDAGE

Arterial Circulation.—In one animal the main artery of the cecal appendage was ligated, and the appendage was removed in forty-eight hours. The specimen was firmly contracted and very white. Sections showed a normal appendage. In

another animal 1 cc. of a broth culture of Staph. aureus-haemolyticus was injected into the appendical artery, and the vein was then ligated. Within twenty-four hours the cecal appendage was acutely inflamed.

Venous Circulation.—In one dog all the veins to the cecal appendage were ligated, and the specimen was removed in forty-eight hours. There was rather marked vascular congestion, but no acute inflammatory changes in the wall.

Combined Circulation.—In two dogs the entire mesentery to the cecal appendage was cut and ligated. The specimens were removed in twenty-four and forty-eight hours. Both showed gangrene of the distal third only. These experiments seem to indicate that in the dog a considerable vascular embarrassment of the cecal appendage is fairly well tolerated, if the continuity of the lumen is not disturbed. A rich collateral circulation from the cecum through the base of the appendage explains the lack of uniform positive changes throughout the organ (table 16).

TABLE 16.—*Results of Circulatory Experiments*

Dog No.	Time, Hr.	Procedure	Gross Description	Diagnosis
99	48	Ligation of arteries of cecal appendage	Contracted and white	Normal
102	24	Injection of hemolytic staphylococci into artery	Edema and hemorrhage	Acute appendicitis
106	48	Ligation of veins of cecal appendage	Congestion in deep layers	Normal
110	24	Severance of entire mesentery	Gangrene of distal third	Gangrenous appendicitis
112	48	Severance of entire mesentery	Gangrene of distal third	Gangrenous appendicitis

TABLE 17.—*Result of Trauma to the Wall of the Cecal Appendage*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
47	48	Few adhesions; cecal appendage empty and relaxed; blood vessels dilated; petechiae in serosa	Gram-positive diplococci; gram-negative diplococci and rods	Acute appendicitis
48	6	Bloody peritoneal fluid; cecal appendage hemorrhagic; one spot of gangrene	.....	Acute appendicitis

MISCELLANEOUS EXPERIMENTS

Trauma to the Wall of the Cecal Appendage.—In two dogs the cecum was severely traumatized manually between the thumb and the fingers. The specimens were excised in six and forty-eight hours, respectively. Edema, hemorrhage and dense leukocytic infiltration were in evidence. The microscopic picture in these instances could not be distinguished from the acute inflammatory changes induced by the other types of experiment (table 17).

Transplantation of a Vascularized Cecal Appendage onto the Duodenum and the Descending Colon.—In two dogs the cecum was severed from the colon and anastomosed end to side to the duodenum. One was removed in ninety-six hours and the other in seven days. The sections were normal.

Two similar transplants were made onto the descending colon, the terminal few inches of the ileum with the cecum attached (after closing the cecum at

the site of section from the ascending colon) being sutured end to side to the descending colon. In such an experiment the cecal appendage was really a blind diverticular pouch of the descending colon. These pouches were excised after many weeks and were found to be distended by a mucoid material. The sections showed no evidence of inflammation (table 18).

Severance of the Cecal Appendage from the Colon.—This procedure was done in two dogs, and the lumen of the cecal appendage was left open after closing the

TABLE 18.—*Result of Transplantation of Cecal Appendage onto the Duodenum*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
35	96	Lumen of the cecal appendage patent and continuous with that of duodenum; contents frothy and similar to that in duodenum	Very sparse organisms; gram-positive diplococci and gram-negative rods; same in duodenum and cecal appendage	Serositis
36	168	Firmly healed and anastomosis in good condition	Very rare gram-positive diplococci	Normal

TABLE 19.—*Result of Severing the Cecal Appendage from the Colon*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
37	96	Few adhesions; no fluid or pus; cecal appendage edematous and serosa covered by exudate; lumen open and contained clear mucus	Very sparse organisms; gram-positive diplococci; gram-negative rods	Peritonitis
38	144	Many adhesions; cecal appendage sealed by omentum and covered by yellow exudate; mucus in lumen	Very sparse organisms; gram-positive diplococci	Peritonitis

TABLE 20.—*Result of the Injection of Peritoneal Exudate into the Wall of the Cecal Appendage*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
49	36	Omentum adherent over edematous cecal appendage; hemorrhagic throughout and gangrenous at injection sites; abscesses not ruptured	Gram-positive diplococci and rods; gram-negative diplococci, rods and streptococci	Abscesses in wall
50	36	Distal abscess ruptured externally and walled off by omentum; proximal abscess ruptured internally; crater filled with yellow necrotic tissue; no perforations	Gram-positive diplococci and rods; gram-negative diplococci, rods and streptococci	Abscesses in wall

colon. These animals were again operated on in ninety-six hours and six days, respectively. There was minimal localized peritonitis. The cecal appendages contained a small amount of clear mucoid secretion containing very sparse organisms (table 19).

Injection of Exudate Into the Wall of the Cecal Appendage.—In two dogs a small amount of virulent peritoneal exudate was injected into the wall of the cecal appendage. The specimens excised after thirty-six hours showed abscesses with central areas of necrosis (table 20).

Injection of Phenol into the Lumen of the Cecal Appendage.—In two dogs 1 cc. of concentrated phenol was injected into the lumen of the cecal appendage. The appendages were excised in forty-eight hours and five days, respectively, and found to exhibit marked hemorrhage and necrosis of the inner layers with diffuse infiltration (table 21).

Measurement of Pressure Developed in Obstructed Cecal Appendages.—In ten dogs with cecal appendages obstructed for twenty-four hours, an attempt was made to measure the fluid pressure spontaneously developed within the lumen. In no instance were satisfactory determinations possible because of the viscous nature of the fluid within the lumen.

Relation of Catharsis to Perforation of the Cecal Appendage.—In eight dogs the cecal appendage was obstructed for twenty-four hours, and large doses of

TABLE 21.—*Result of the Injection of Phenol into the Lumen of the Cecal Appendage*

Dog No.	Time, Hr.	Gross Description	Bacteriologic Picture	Diagnosis
54	48	Cecal appendage edematous and serosa shows petechiae; mucosa sloughing and contents bloody	Gram-positive diplococci and rods; gram-negative diplococci and rods	Acute appendicitis
55	120	Grossly normal; mucosa sloughing and contents bloody	Gram-positive diplococci and bacilli; gram-positive spore-forming bacilli, diplococci and large bacilli	Acute appendicitis

TABLE 22.—*Effect of Release of Obstruction on Gangrenous Cecal Appendage*

Dog No.	Gross Description of Specimen		Diagnosis
	After 24 Hours of Obstruction	After 7 Days of Obstruction	
89	Gangrenous cecal appendage	Adhesions, edema and hemorrhage	Acute mild appendicitis
91	Grossly normal cecal appendage	Edema and congestion	Acute appendicitis
93	Gangrenous cecal appendage	Adhesions, edema and hemorrhage	Acute appendicitis
111	Edema and hemorrhage	Edema	Acute appendicitis
113	Edema, congestion and distention	Edema and hemorrhage	Acute appendicitis

physostigmine were given to four and croton oil to four. In every case severe diarrhea developed, but in no instance was there a perforation within twenty-four hours. Similarly, no manifest ill effects were observed from purgation with saline solution of the two dogs with the cecal appendage anastomosed to the descending colon.

Healing of Gangrenous Cecal Appendages.—In five dogs the cecal appendage was obstructed for twenty-four hours, after which the obstruction was released. Laparotomy was again performed six days later. The appendages showed rather dense omental adhesions over their surfaces and were grossly edematous. Some showed old hemorrhages, and all exhibited evidence of subsiding acute inflammatory changes. In two animals gangrene was produced by twenty-four hours of obstruction; the occluding ligature was then released, and the appendages were removed after six weeks. These were normal except for slight fibrosis of the submucosa. No strictures developed (table 22).

Bacteria in the Tissues.—In the cecal appendages excised following the maintenance of increased intraluminal pressure a variety of bacteria were found in all layers of the gangrenous specimens. The permeation of bacteria through the layers of the wall of the bowel was less evident in the nongangrenous specimens. Organisms were found in the tissues in all of the pressure experiments in which gangrene occurred. Bacteria were observed in all layers. In the nongangrenous specimens, organisms were found usually in the mucosa and the immediately subjacent layer. Sections from fifty-four representative specimens obtained in the other experiments reported on here were also studied. Bacteria were found in the tissues of the wall of the cecal appendage in only fourteen of the nongangrenous specimens. These were observed largely in the submucous and muscular layers.

COMMENT

The results of these experiments point toward two important agencies in the occurrence of inflammation in the cecal appendage, viz.: (1) obstruction and (2) infection. The pathologic picture, as it is known in appendicitis, does not occur in the cecal appendage of the dog following obstruction if the lumen is previously washed out. At the same time, infection without obstruction will not bring about the disease process. In the cecal appendage of the dog, to be sure, the factor of obstruction has to be artificially brought out, for the appendage connects with the cecum by a wide-mouthed communication. The element of infection, as in the human appendix, is, however, uniformly there in the invariable presence of bacteria. The presence of obstruction is necessary to initiate the changes, and the more complete the obstruction the more marked the changes. Invasion of the wall of the bowel by bacteria occurs as the circulatory changes progress.

The sequence of events as observed appear to mimic closely what obtains in closed intestinal loops. Such loops, first made by Whipple [16] and his associates to study the phenomena accompanying obstruction of the bowel, have taught much relative to the behavior of the bowel under conditions of obstruction. Owing to continued profuse secretion from jejunal loops, they usually rupture, as absorption of fluid at this level in the bowel is not as prominent as secretion. Burget and his associates [17] had dogs survive with closed loops of small intestine, however, for relatively long periods of time when they frequently aspirated the content accumulating within the loop. In the main, the shorter the loop, the greater is the hazard of perforation. Whereas closed loops of colon containing feces are likely to rupture, short, washed closed loops of colon appear to give no trouble. This would appear, also, to

16. Stone, H. B.; Bernheim, B. M., and Whipple, G. H.: Intestinal Obstruction: A Study of the Toxic Factors, Bull. Johns Hopkins Hosp. **23**:159, 1912.

17. Burget, G. E.; Martzloff, K. H.; Suckow, G. R., and Thornton, R. C. B.: The Closed Intestinal Loop: The Relation of Intraloop (Jejunum) Pressure to the Clinical Condition of the Animal, Arch. Surg. **21**:829 (Nov.) 1930.

be the significant mechanism in the experimental production of inflammation of the cecal appendage.

The late Van Zwalenburg [18] was one of the first to point out the significance of the obstructive factor in the experimental production of inflammation in the cecal appendage of the dog. In 1904 he published the results of experiments in which he maintained distention of the cecal appendage of the dog over a period of four hours under a constant intraluminal pressure of 150 mm. of mercury. After the lapse of twenty-four hours, the specimen was excised; gangrenous changes were usually present. In our study we found that relatively low pressures (from 8 to 15 cm. of water) maintained from six to eighteen hours will bring about gangrenous changes. In ileal closed loops 18 inches (45.7 cm.) in length subjected to a constant sustained intraluminal pressure of 20 cm. of water from twenty-eight to thirty-two hours, Sperling and Wangensteen [19] observed necrosis of the wall with accompanying loss of viability and evidence of abnormal permeability of the tissue. When a pressure of 40 cm. of water was employed, similar changes were obtained in seventeen hours.

Boit and Heyde [20] and Heile [21] and more recently Eichoff and Pfannenstiel [22] also concluded that obstruction is an important item in the experimental production of a picture akin to that observed in appendicitis. The literature is large, and no attempt will be here made to review it systematically.

CLINICAL OBSERVATIONS

This study has dealt essentially with the experimental features of the problem. During this same time, however, opportunity has been afforded for clinical observations which permit of conclusions which tend to corroborate the thesis relating to the significance of the obstructive factor set forth in this experimental investigation. The pathologic

18. Van Zwalenburg, C.: Obstruction and Consequent Distension the Cause of Appendicitis as Proved by Cases and by Experimental Appendicitis in Dogs, J. A. M. A. **42**:820 (March 26) 1904.

19. Sperling, Louis, and Wangensteen, O. H.: Unpublished data.

20. Boit, H.: Experimentelle Entzündung des Blinddarmhanges beim Hunde, Verhandl. d. deutsch. Gesellsch. f. Chir. **42**:234, 1912; Berl. klin. Wchnschr. **49**: 812, 1912. Boit, H., and Heyde, M.: Experimentelle Untersuchungen zur Aetiologie den Wurmfortsatzentzündung, Beitr. z. klin. Chir. **79**:271, 1912.

21. Heile, B.: Ueber die Folgezustände nach mechanischem Abschluss des Blinddarmanhanges bei Mensch und Thier, Verhandl. d. deutsch. Gesellsch. f. Chir. **42**:228, 1912; Ueber die Entstehung der Entzündungen am Blinddarmanhang auf bakteriologischer und experimenteller Grundlage, Mitt. a. d. Grenzgeb. d. Med. u. Chir. **26**:345, 1913; Experimentelle Appendizitis, München. med. Wchnschr. **6**:209, 1925.

22. Eichoff, E., and Pfannenstiel, W.: Experimentelle Untersuchungen zur Aetiologie der Appendizitis, Beitr. z. klin. Chir. **151**:171, 1930

aspects of the clinical problem will be elaborated on by one of us (W. F. B.) at a later date. The clinical observations here related were made on patients in the surgical wards of the Minneapolis General Hospital (W. F. B.).

During the current year, the operative specimens from ninety-one patients with conditions diagnosed pathologically as acute appendicitis were available for examination. With the cooperation of the operating surgeons, it was possible to get appendixes on which no clamps had been placed during the procedure of operative removal. The gross appearance of the appendix was carefully noted, and great care was taken not to traumatize it by palpation. The specimen was then placed in a diluted solution of formaldehyde (1:10) and allowed to stand for twenty-four hours before it was cut. At this time the appendix was slit longitudinally with a sharp Bard-Parker knife much in the manner in which one bivalves a plaster cast, leaving anterior and

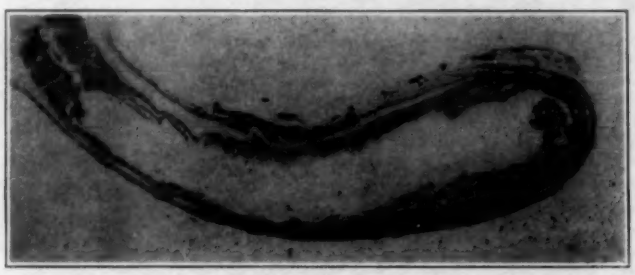

Fig. 6.—Photomicrograph of a section of an obstructed gangrenous appendix showing the distal dilatation, thinning of the wall, thrombosis of vessels and erosion of the mucosa. Proximal to the area occupied by the fecalith, the wall is shown to be practically normal; dilatation of the lumen is absent.

posterior shells. The presence or absence of appendical concretions, narrowing or dilatation of the lumen, the presence of strictures and the state of the appendical wall at various places were all carefully noted. Histologic examination of the tissues were made in representative areas in the manner outlined in this experimental study.

The gross appearance of the ninety-one appendixes led to the following pathologic classification as to the type of appendicitis: acute suppurative appendicitis, forty-three cases; nonperforative gangrenous appendicitis, nineteen, and perforative gangrenous appendicitis, twenty-nine. Clinically, the cases in which collections of free exudate were found outside the appendix at the time of operation all belonged to the group of cases of perforative appendicitis. The only fatalities, as one might well anticipate, occurred in this group. In three of the fatal cases the patient died of suppurative complications consequent on peritoneal infection (figs. 6 and 7).

Of the forty-three cases of acute suppurative appendicitis, an appendical concretion had caused a definite obstruction in eighteen, or 44 per cent. In the thirteen additional cases obstruction appeared to have developed through the agency of a stricture, a sharp kink or an abnormal band. When these extrinsic obstructive phenomena are included with the intrinsic obstructions, the total for the group is 72 per cent. Of the forty-eight cases of gangrenous appendicitis, an appendicolith had brought about an obstructive mechanism in thirty-eight, or 80 per cent. Of the ten remaining cases, a stricture or definite extrinsic

Fig. 7.—Photomicrograph of a section of the appendix in figure 6 showing the necrotic changes just distal to the point of obstruction.

obstruction was present in every instance, establishing an obstructive causative mechanism in 100 per cent of the cases.

The fecaliths were large brownish bodies; in many instances there were more than one. Occasionally, these concretions were grayish white and unusually hard. On cut section, they were always laminated, indicating that they had formed rather gradually and had probably attained an age considerably beyond that of fecal masses in the bowel. A central nucleus of a bit of undigested cellulose from the intestinal canal, or less commonly a foreign body such as a tooth brush bristle, was

the rule. Several of these appendical concretions were subjected to chemical analysis for bilirubin, urobilin, urobilinogen and copronegrin. These tests, which were performed for us by Dr. Cecil J. Watson, were negative for bile pigment. These observations tend strongly to support the impression that these concretions arose essentially in the appendical lumen, even though the nucleus came from the intestinal canal. The formation of such enteroliths in the intestinal canal under conditions of stasis is well known. Such an occurrence would suggest that the appendix may frequently behave somewhat as a closed loop as far as the remainder of the intestinal canal is concerned, at times permitting material to enter but precluding free extrusion of intestinal content from it [23] (figs. 8 and 9).

Fig. 8.—Longitudinal section of an acutely inflamed appendix showing a large laminated fecalith obstructing the lumen. Distal dilatation of the lumen with mucosal ulceration is seen. These changes are not present proximal to the obstruction.

One of us (O. H. W.), with the cooperation of Dr. Wallace Ritchie, resident surgeon, and other house officers at the University Hospital, has recently subjected this premise to experimental inquiry. When the uninflamed appendix was removed in the interval, opportunity was afforded to determine whether the appendix might behave as a closed loop. A needle attached to a column of water was inserted into the appendical lumen at the distal end. Invariably the pressure of a column of water 40 cm. in height could be supported without a drop of water running into the cecum. In many instances a pressure of from 60 to 80 cm. of water would be sustained. In a few instances in which there

23. Dr. G. E. Burget, professor of physiology at the University of Oregon Medical School, who has studied "closed loops" over a prolonged period, informs us that lamination was never observed in the material which formed in such loops.

had been previous inflammation, a column of water of more than 100 cm. in height failed to cause the water to enter the cecum. In preparations of the cecum and appendix, as obtained at autopsy, it was uniformly observed that lesser pressures were withstood. The latter finding suggests that the obstacle to inflow of water from the appendix into the cecum may be occasioned by a sphincter-like mechanism. In 1847 Gerlach [24] suggested the presence of such a valve, but its action as a sphincter has been denied by anatomists. These observations lend tenable support for the existence of such a mechanism. How in turn

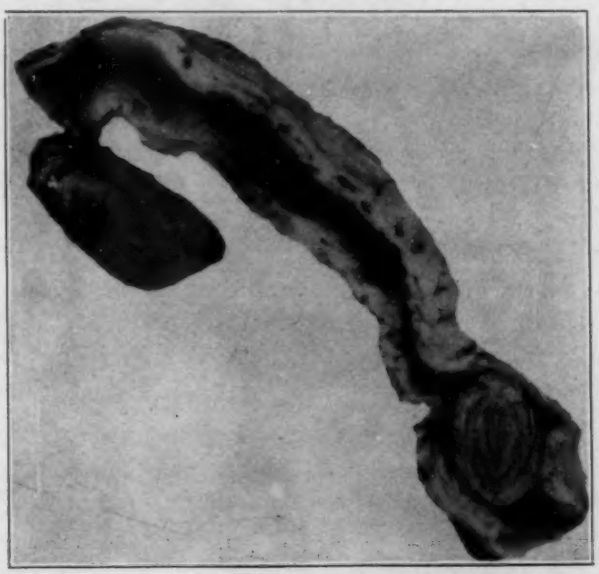

Fig. 9.—Longitudinal section of a completely gangrenous appendix which had spontaneously amputated itself at the cecum. The fecalith at the tip is maintained in its position by a connective tissue stricture. The second fecalith was found free in the abscess surrounding the appendix.

a sphincter-like mechanism may be reflexly influenced through its extrinsic nerve supply is a matter which permits of some speculation. The findings relating to this study will be described elsewhere at greater length.

COMMENT

In the early literature on appendicitis, the significance of the mechanical element in the occurrence of perforation of the appendix enjoyed more credence than it does today. In an admirable little monograph,

24. Gerlach, L.: Beobachtung einer tödliche Peritonitis als Folge einer Perforation des Wurmfortsatzes, Ztschr. f. path. Med. **6**:12, 1847.

too little known, written by Adolph Volz [25] in 1846, the importance of the appendical concretion in the complication of perforation received full recognition. Volz expressed the belief that perforation occurred through the agency of pressure erosion over the concretion, and even today one occasionally hears of this causal relationship between the appendicolith and the perforation. Those familiar with the behavior of closed loops know that whereas perforation may occur near the site of occlusion, in the main, rupture is more likely to occur at the weakest point between the two ends of the short loop.[26] Matterstock [27] in 1880 and Fitz [1] in 1886 again gave important consideration to the obstructive element in the occurrence of perforation of the appendix, as did Maaloe [28] also in 1908. More recently Wilkie [29] designated clinical cases of appendicitis as instances of acute suppurative appendicitis and of appendicular obstruction. Cutler,[30] Westphal [31] and Williams and Boggon [32] have again recently emphasized the importance of the mechanical factors in the genesis of appendicitis.

Meleney and his associates,[33] in a splendid paper on the subject of suppurative appendicitis, pointed out that deaths as well as the complications of appendicitis occurred almost solely in the cases in which the appendix perforated. In a recent communication, Meleney [34] wrote: "You are quite right in believing that I feel that fecal concretions in the appendix are frequently responsible for the initiation of appendiceal inflammation."

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25. Volz, A.: Die durch Kothsteine bedingte Durchbohrung des Wurmfortsatzes, die häufig verkannte Ursache einer gefährlichen Peritonitis und deren Behandlung mit Opium, Carlsruhe, C. F. Müller, 1846.

26. Van Beuren, F. T.: Mechanism of Intestinal Perforation Due to Distension, Ann. Surg. **83**:69, 1926.

27. Matterstock, G. K.: Perityphlitis, in Gerhardt, C.: Handbuch der Kinderkrankheiten, Tübingen, H. Laupp, 1880, vol. 4, pp. 2 and 893.

28. Maaloe, C. U.: Histopatologiske studier over processus vermiformis, Kommission hos Jacob Lund, København, 1908.

29. Wilkie, D. P. D.: Acute Appendicitis and Acute Appendicular Obstruction, Brit. M. J. **2**:959, 1914.

30. Cutler, O. I.: Mild Acute Appendicitis: Appendical Obstruction, Arch. Surg. **31**:729 (Nov.) 1935.

31. Westphal, K.: Appendizitis und Kotstein als Folge gestörter Appendixfunktion, Deutsche med. Wchnschr. **60**:499 and 600, 1934.

32. Williams, B. W., and Boggon, R. H.: Mechanics of Appendicitis, Lancet **1**:9, 1934.

33. Meleney, F. W.; Harvey, H. D., and Jern, H. Z.: Peritonitis: I. The Correlation of the Bacteriology of the Peritoneal Exudate and the Clinical Course of the Disease in One Hundred and Six Cases of Peritonitis, Arch. Surg. **22**:1 (Jan.) 1931.

34. Meleney, F. W.: Personal communication to the authors.

The increased intraluminal tension in the gallbladder occasioned by impaction of a calculus in the cystic duct and the occurrence of gangrene in the cecal wall consequent on obstruction of the pelvic colon and the closed loop so formed, owing to the competence of the proximal ileocecal sphincter as well as the gangrene occasionally observed in the urinary bladder as the result of infection, attest the importance of the mechanical element for the occurrence of perforation in the obstructed appendix.

Another place in the intestinal canal where one commonly sees perforation, as a consequence of obstruction and infection, is in the crypt of the anorectal region, inflammation of which not infrequently eventuates in ischiorectal abscess and an external rectal fistula. The significance of the mechanical element for this sequence of events is at once apparent. Prominent lymphatic follicles intervene between the semilunar pockets. Normally a free secretion of mucus serves to extrude any small particles which find their way into them. The lodgment of foreign bodies in these pockets readily sets up inflammatory changes in the lymphoid follicles, which in turn swell and further preclude extrusion of the foreign body. Perforation of the rectal wall occurs as a direct consequence. In the occurrence of this sequence of events, appendicitis probably has a close counterpart. The suggestion of Aschoff that the crypts of Lieberkühn in the empty appendix make good hiding places for small foreign bodies as well as bacteria is particularly good. Obstruction, however, would appear to be the factor of greatest moment in permitting such foreign bodies or bacteria to find their way through the coats of the appendical wall. Similarly swelling of the lymphoid tissue in the nasopharynx undoubtedly plays an important rôle in obstructing the eustachian tube and in causing perforation of the ear drum in otitis media.

The clinical picture itself in acute appendicitis accentuates the importance of the mechanical features. It is essentially early a colic in which a febrile disturbance, usually of low grade, indicates the onset of inflammation and suppuration consequent on the obstruction.

The more prevalent medical opinion, however, appears to be that in most instances acute appendicitis is of infectious origin.[35] The expressions of Aschoff on this subject have undoubtedly been important in throwing into practical discard the older ideas relating to the significance of the obstructive element. The suggestion of a specific infection is most intriguing. And to be certain, one sees clinical examples which would lend credence for the possibility of such an

35. Fonio, A.: Zur Frage der Kontagionsmöglichkeit der Appendicitis, Schweiz. med. Wchnschr. **58**:597, 1928. Walther, K.: Zur Infektiosität der Appendicitis: Untersuchungen über epidemieartiges Auftreten im Reichsheer, Arch. f. klin. Chir. **166**:72, 1931. Adrian.[8] Rosenow.[8] Aschoff.[9c]

occurrence in the appendix, viz., the epidemics of infection of the upper respiratory tract in which the incidence of laryngitis or tracheitis is uniformly high or the instances in which the occurrence of intestinal cramps and diarrhea are frequent, and others in which vomiting is a frequent disturbance. However interesting may be the finding by Aschoff of a relatively pure culture of an organism in the distal third of the normal appendix, uncontaminated by the more sociable organisms in the more proximal reaches of the appendix, the finding of this bacterium as the sole or the predominant organism present in the suppurative process of appendicitis does not establish appendicitis as a specific bacterial disease. Such organisms do not produce inflammation in the cecal appendage of the dog unless it is obstructed, and most investigators have found that a number of organisms may be present in the acutely inflamed appendix, as did also Aschoff at times. What the factors are which incite the organisms to activity have not been clarified. It is our belief that the usual provocation is obstruction, and our observation has been that a number of bacteria, corresponding to the flora of the bowel, may be found in the suppurative process. The bacteriologic features of the problem will be elaborated on later by one of us (W. F. B.). What the explanation of so-called epidemics of appendicitis is is not apparent. In the main, statistical studies indicate that appendicitis divides itself fairly evenly throughout the year.

THE PROBABLE SEQUENCE OF EVENTS IN APPENDICITIS

The facts which stand out prominently concerning the human vermiform appendix are that it is a very narrow, hollow tube, closed at its far end with an unusual amount of lymphoid tissue in its wall. It would also appear that the appendix is a potential closed loop, in that something akin to a sphincter-like mechanism at its juncture with the cecum interferes with evacuation of material which has found its way into the appendix. The occurrence of obstructive appendical concretions in the lumen in a large percentage of all cases of acute suppurative appendicitis suggests the presence of such a mechanism. These concretions are usually laminated, indicating that they have been some time in forming. They do not react positively to any of the usual tests for bile pigments. Even though the central nucleus comes from the intestinal canal, the larger portion of these concretions are formed in situ. That acute suppuration of the appendix may occur on the basis of obstruction in the absence of such concretions appears likely in that the appendix apparently behaves like a potential closed loop. With evacuation of the content of the appendix interfered with, a struggle for hydraulic equilibrium ensues in the lumen. Blood comes into the appendix under the motive force of systolic blood pressure. When the sphincter-like

mechanism at the base of the appendix resists evacuation of its content, the lumen distends. The increase in intraluminal pressure interferes with venous return; with maintenance of sustained intraluminal pressure for a few hours, the tiny veins rupture and hemorrhage occurs. Owing to the poor oxygenation of the tissue, it is a matter of no great difficulty for the ever present bacteria to invade the submucosal lymphoid tissue. The swelling is thereby increased, and the inflammatory process is in full swing.

If bacteria were not present in the lumen of the appendix its obstruction would be no more hazardous than the strangulation of a small ovarian cyst or torsion of a testis.

SIGNIFICANCE OF THE OBSERVATIONS HERE REPORTED

The surgeon has become rather apologetic over operating for the removal of an acutely inflamed appendix when operation failed to disclose an obviously menacing organ. He has in a sense become the sensitized victim of the pathologist, who is likely, when he fails to find evidence of acute inflammation in the appendix, to decry the operation as having been unnecessary. More and more, however, the significance of altered function must become a consideration important to the pathologist as well as to the surgeon.

The serious threat always latent in the bad anatomic arrangement of the appendix, which man gives no immediate promise of outgrowing, fully justifies its prophylactic removal during the course of other abdominal operations, where this procedure may be done without additional risk. In the presence of pain in the right side of the abdomen, when other causes have been adequately excluded, the removal of the appendix in the absence of previous acute attacks would appear to be fully justified, pathologic opinion to the contrary notwithstanding. Now it is significant that C. W. Mayo,[36] before the Western Surgical Association two years ago, reported satisfactory relief from symptoms after appendectomy in more than 70 per cent of patients with indefinite pain on the right side of the abdomen, when a careful preoperative examination excluded other palpable causes. Sources for abuse in the advocacy of promiscuous appendectomy are obvious. The surgeon with an alert and knowing conscience is not likely to advise the operation, however, without just cause. When one recalls that between 18,000 and 20,000 persons die every year from acute appendicitis in this country alone, it is apparent that physicians and patients have given too little credence to the serious import of appendical colic.

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36. Mayo, C. W.: Exploration of Abdomen and Appendectomy for Atypical Symptoms: Results Five Years After Operation in One Hundred Cases, West. J. Surg. **42**:189, 1934.

Aschoff pointed out that autopsy discloses that from 75 to 80 per cent of appendixes in persons in the sixth or seventh decade of life show evidence of previous inflammation.[9b] Obliteration may be observed even in the first decade of life. It is not a physiologic process; it does not happen in the fallopian or eustachian tube or in the urethra or ureter in the absence of an ulcerative process. A ureter maintains its lumen indefinitely after nephrectomy. That appendicitis is a common ailment is therefore at once apparent.

The appendix of the infant frequently maintains the fetal funnel-like attachment to the cecum for the first few years of life. The minute anatomy of the appendix must be carefully scrutinized. In its better understanding, undoubtedly, are to be found facts yet unknown which relate themselves to the problem of appendicitis. Such studies are now under way in the University Hospital Clinic. It appears likely that the anatomy of the appendix is a far more responsible agent in the causation of appendicitis than is the diet.

CONCLUSIONS

From this study we feel that the following conclusions are justified:

1. Obstruction and infection are the two causative factors important in bringing about the picture of acute appendicitis. In the dog complete obstruction of the infected cecal appendage was always followed by inflammation; obstruction of the washed appendage was usually well tolerated. Infection without obstruction did not produce inflammation.

2. The essential inciting factor would appear to be a disturbance in the pressure-distention relationship of the appendix. Sustained intraluminal pressures of from 8 to 15 cm. maintained for from six to eighteen hours invariably were followed by changes in the wall of the cecal appendage.

3. There appears to be a sphincter-like mechanism at the base of the appendix which makes of it a potential closed loop, with all its attendant inherent dangers. This mechanism accounts for the formation of appendical stones or concretions. These are laminated and are formed largely in situ in the appendix, a sign of appendical stasis.

4. Appendical concretions are found as acutely obstructing agents in most instances of perforated appendixes—the group in which mortality occurs.

5. Appreciation of the significance of appendicular colic should lead to a better understanding of the nature of appendicitis. Appendicular obstruction brooks no delay and demands immediate appendectomy.

THE MANAGEMENT OF COMPOUND FRACTURES

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The management of compound fractures is by no means standardized. The methods of treatment are many and varied, although fundamentally the principles are the same. No one method is applicable to all compound fractures. Before deciding on the procedure, consideration must be given to the location and type of fracture, to the condition of the patient and of the wound and to the posttraumatic time factor.

In 1794 Weldon [1] wrote that the "principles in the management of compound fractures" were:

1. To stop hemorrhage.
2. To reduce the bones to their proper situation.
3. To bring every part of the wounded surface into close contact with its opposite surface.
4. To retain both the bones and soft parts in their proper situation until they are united.
5. To moderate the violence of the inflammation.

These principles still hold good.

THERAPY

A compound fracture is an emergency and requires immediate attention. The treatment resolves itself into the care of (1) the patient, (2) the wound and (3) the fracture.

The patient in shock should be treated accordingly, since the local treatment is of no consequence if the patient dies in shock. Active bleeding must be arrested. The patient is placed in the shock position and external heat is applied. Morphine, codeine or a mixture of the hydrochlorides of the opium alkaloids is invaluable for the relief of pain or anxiety. In a fracture of the long bones, traction on the limb or splintage allays pain and helps in the prevention of shock. The fluid balance and blood pressure are maintained by the administration of fluids subcutaneously or intravenously. For hypodermoclysis, physio-

Read before the Surgical Section of the New York Academy of Medicine, March 6, 1936.

1. Weldon, Walter: Observations, Physiological and Chirurgical, on Compound Fractures, Containing an Answer to the Following Question: "What Are the Best Methods of Treating Compound Fractures, According to the Degree of Injury Sustained by the Limb? Southampton, B. Crosby, 1794, vol. 7.

logic solution of sodium chloride or a 2 per cent solution of dextrose in physiologic solution of sodium chloride is advisable, while for infusion, either physiologic solution of sodium chloride or a 10 per cent solution of dextrose may be used. Transfusion of whole blood from a suitable donor is invaluable, especially after hemorrhage.

As soon as the patient has reacted, 1,500 units of tetanus antitoxin are given subcutaneously. The antitoxin should be injected slowly, and one should be on guard for the possibility of an anaphylactic reaction. The administration of a prophylactic dose of polyvalent gas gangrene antitoxin together with the tetanus antitoxin is recommended. My associates and I have been using 2.5 cc. of the Lederle product, which contains Bacillus perfringens, Bacillus Welchii and Bacillus oedematis-maligni antitoxin. In our series of 100 cases there has not been a case of tetanus or of gas gangrene.

In the treatment of a compound fracture much depends on the time element. If a patient is treated within six hours after trauma, provided satisfactory débridement can be done, immediate suture of the wound without drainage is our method of choice. Subsequent to this period the wound should be left wide open or loosely sutured and drained.

As soon as the patient is seen, the wound is covered with a sterile dressing or a towel. If possible, roentgenograms are taken and studied before local treatment is attempted. It is necessary to note the condition of the circulation and to ascertain the presence of any damage to the nerves or tendons. Local treatment should be carried out under superaseptic precautions and with the patient under anesthesia. Grease and grime in and about the wound are removed with gasoline, benzene or kerosene. The wound is then protected with a pad soaked in alcohol. The surrounding skin is gently washed with soap and warm sterile water. The washing should be careful, painstaking and nontraumatic, so as to avoid the dissemination of infection and to prevent further insult to already traumatized tissue. The skin is then carefully dried and painted with tincture of iodine. The pad covering the wound is now removed. The wound is gently washed with warm sterile water and soap, and this procedure is followed by flushing with hot ether. When the wound has become fairly dry, it is flooded with tincture of iodine. Of 100 patients so treated, infection developed in only 9. I feel that this relative freedom from infections is due to the proper washing and gentle handling of the part and not to the use of so-called antiseptics. I believe that all physicians are in accord with the fact that too much should not be expected from the use of antiseptics. After the part has been properly cleansed, foreign bodies are removed, and all devitalized or bruised tissues are excised. Loose pieces of bone, when covered by periosteum, should be retained.

Débridement should consist of the complete removal of actually damaged tissue and not in the sacrifice of a great deal of healthy tissue, as practiced during and immediately after the World War. I am in favor of excising small wounds and then enlarging them so as to allow for free inspection of the deeper structures. Débridement as such was first mentioned by Larrey,[2] who was chief surgeon to Napoleon's army.

Severed nerves and tendons are immediately repaired. Otherwise, there should be little suturing of the deep structures and then only with catgut. The skin is closed with interrupted dermal sutures so placed and tied as to allow for swelling and drainage. Tight closure will cause aseptic necrosis and a resultant loss of tissue. The fracture is then treated as a simple one. Deep and bloody wounds should be drained with rubber tissue or a pipe cleaner. Pipe cleaners as drains were first brought to my attention by Moorhead.[3]

In cases in which the edges of the wound cannot be approximated without tension, releasing incisions should be made on one or both sides of the original wound and the original wound closed. If necessary, the subsequent incisions are allowed to remain open. This procedure covers the bone with healthy tissue.

Primosecondary suturing of the wound, as recommended by Moorhead,[3] should be seriously considered. According to the technic advised by him, interrupted nonabsorbable sutures are introduced but are not tied. A sterile dressing is applied to the wound, and if at the expiration of from forty-eight to seventy-two hours there is no evidence of infection, the sutures are tied. Union by primary intention follows.

When the wound cannot be closed because of badly contused tissues or a marked loss of soft structures, one is confronted with a serious problem. If the bone remains exposed, necrosis follows. Under these circumstances I believe that the Orr treatment is the method of choice. As soon as healthy granulations appear, the wound should be covered with pinch grafts. Early skin grafting lessens the period of disability.

In a compound fracture of the skull the scalp is shaved and then prepared as described. The edges of the wound should be excised, bleeding carefully attended to and any detached fragments of bone, dirt and hair removed. Depressed bone should be elevated if focal signs of infection are present. Torn dura should be closed, if possible. I am in accord with Temple Fay,[4] who stated: "The one clear-cut

2. Larrey, D. J.: Mémoires de chirurgie militaire et campagnes, Paris, J. Smith, 1812.

3. Moorhead, John J.: Personal observation.

4. Fay, Temple: The Treatment of Acute and Chronic Cases of Cerebral Trauma, by Methods of Dehydration, Ann. Surg. **101**:76 (Jan.) 1935.

indication for prompt surgery after cranial trauma is the presence of a compounded fracture of the skull, where foreign bodies, fragments of bone, hair or dirt may have entered the brain substance. Here the first principle is cleanliness and protection of the brain structures against infection. Débridement and proper repair of the wound should be done as promptly as possible, instituting appropriate drainage if necessary."

In the management of compound fractures, differences of opinion existed a century and more ago as they do today. As previously mentioned, Larrey [2] advised early débridement and closure. Beaumont [5] one hundred and five years ago, in discussing the treatment of compound fractures, wrote: "It appeared to me, that by maintaining in compound fractures a continued exclusion of the atmosphere from the broken surfaces of the bone, union might proceed, ceteris paribus, as rapidly as in simple fractures, and with almost as little danger." He recommended a dressing of the wound and condemned the use of splints. He further stated that "by incrusting in Plaster of Paris a fractured leg" shortening is prevented. In concluding the article, he wrote: "If against the mode I have proposed of treating compound fractures, it should be urged that one cannot daily examine the limb in order to ascertain its state, I would say that any examination of the local malady must be unnecessary so long as there is little constitutional disturbance. . . ." Walker [6] in 1845 recommended free drainage and the open treatment. Recently, Sherman [7] expressed the belief that if the fracture cannot be reduced the wound should be enlarged and reduction obtained and maintained by the use of plates and screws, but he opposed utilizing encircling bands and wires. He advised removal of plates in about four to five weeks after bony fixation has occurred. In his opinion, extensively comminuted fractures should not be operated on, treatment by traction and suspension being preferable. Pfeiffer and Smyth [8] are strong advocates of the Orr treatment for compound fractures.

In a fracture of the long bones, immediate traction should be made on the limb to prevent shock, to obliterate dead spaces and to avoid the collection of blood and serum therein. "Splint 'em where they lie"

5. Beaumont, W. Rawlins: Observations and Experiments on a New Mode of Treating Fractures of the Leg and Forearm, Especially Compound Fractures, London, Longman and others, 1831, p. 8.

6. Walker, W. J.: An Essay on the Treatment of Compound and Complicated Fractures, Boston, Crocker & Brewster, 1845, p. 8.

7. Sherman, W. O'Neil: The Operative Treatment of Fractures, in Nelson Loose-Leaf Surgery, New York, Thomas Nelson & Sons, 1927, vol. 3, pp. 405-457.

8. Pfeiffer, D. B., and Smyth, C. M., Jr.: The Treatment of Compound Fractures with Special Reference to the Orr Method, Ann. Surg. **102**:1059 (Dec.) 1935.

is good advice in all fractures of long bones. It is of the greatest importance in compound fractures, since proper early splintage will prevent the dissemination of infection within the tissues and avoid further trauma to the soft parts by the fragments.

Protruding bone should be carefully inspected before being replaced. If the ends are soiled, scrubbing with soap and warm water is allowable. When a fracture can be reduced by manual manipulation, this should be done before the wound is closed. Reduction is maintained by encasing the part in plaster of paris. When necessary, a window is cut in the cast to allow for the removal of drains and for the dressing of the wound.

In a fracture with overriding or with much comminution the procedure is traction and suspension. The introduction of a Kirschner wire is a simple operation, causing practically no destruction to either the soft structures or the bone. It is introduced through healthy bone distal to the site of the fracture. By paying careful attention to the alinement of the limb and by taking repeated roentgenograms, one can guide the position of the fragments. Dressing of the wounds is easy and can be done with little or no discomfort to the patient. When the overriding has been corrected and reduction obtained, the following procedures may be employed:

1. The part may be allowed to remain in suspension with lessened traction until union of the fragments has occurred. During traction, one must guard against distraction of the fragments.

2. The part may be immobilized in a plaster of paris cast, the traction wire being allowed to remain in situ. After seventy-two hours, roentgenograms are taken. If the fragments have not slipped, the traction wire may be removed.

In our series of 100 cases of fracture, the two sites that gave the poorest end-results were: (1) both bones of the leg and (2) the bones of the hand. It should be borne in mind that because of the anterior bowing of the tibia, the weight-bearing line of the leg runs slightly anterior to the middle of the ankle joint. When dishing occurs, the weight-bearing line moves backward, and the weight of the body is carried on the heel. The muscles of the calf are stretched over the angulated bone and pull on the os calcis so as to bring the heel up and the toes down. As a result, the function of the part is limited and painful. It is evident, therefore, that in the treatment of a fracture of the leg, the normal anterior bowing of the tibia must be retained or even slightly exaggerated.

All of our compound fractures of the bones of the hand were due to crushing violence. Most of the wounds were covered with grease and grime. The tissues were so distorted that satisfactory débridement

Fig. 1.—Roentgenogram showing a fracture of the shafts of the metacarpals of the third, fourth and fifth fingers, with marked displacement. (Published through the courtesy of Dr. John J. Moorhead.)

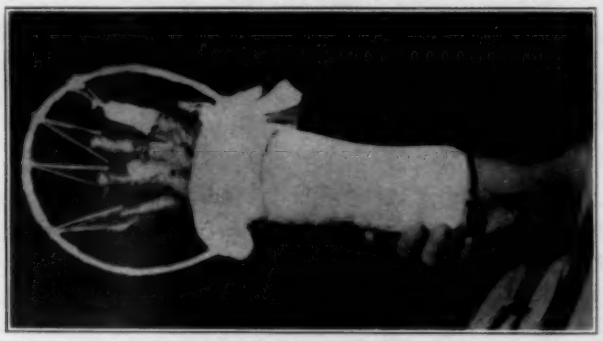

Fig. 2.—The method used for obtaining traction in a case of fracture of the shafts of the metacarpals. (Published through the courtesy of Dr. John J. Moorhead.)

Fig. 3.—Roentgenogram showing the reduction obtained by the method described. Note the needles through the terminal portions of the phalanges of the third, fourth and fifth fingers. (Published through the courtesy of Dr. John J. Moorhead.)

was impossible. Yet, infections were surprisingly infrequent. Fractures of the metacarpals and phalanges are best treated by traction and suspension (fig. 1). A banjo splint is applied to the flexor surface of the forearm (fig. 1). Sure and steady traction can be made by passing a stout silk thread through the finger-nail or about a needle through the pulp of the fingers or terminal portion of the phalanges (fig. 2). The thread is then fastened and tied to the splint. Traction can be increased by twisting the thread in the manner of a Spanish windlass. The normal concavity on the flexor surfaces of the metacarpals and phalanges must be maintained; it can be done by stretching a piece of bandage across the splint and resting the flexor surface of the fracture on it. Obviously, dressing of the wound is simple. Figure 3 shows the reduction obtained.

ANALYSIS OF FRACTURES

Fifteen per cent of all the fractures seen at the New York Post-Graduate Hospital and the Reconstruction Hospital over a five year period were compound. From a study of 100 compound fractures, we obtained the following data:

Sex Incidence

88 male	12 female

Age Incidence (no. of patients)

1 yr. to 10 years	6
10 " " 20 "	6
20 " " 30 "	33
30 " " 40 "	18
40 " " 50 "	24
50 " " 60 "	7
60 " " 70 "	6

Sites of Fracture (no. of cases)

Skull	21
Lumbar portion of spine	1
Jaw	4
Nasal bones	6
Humerus	6
Radius and ulna	6
Metacarpals and phalanges	18
Femur	6
Tibia and fibula	26
Tibia	3
Pott's fracture	3

Causes

Automobile accidents	74 fractures
Other violences	26 fractures, of which 1 was the result of a bullet

Infections (total, 9 cases)

Moderate; subsided without involvement of bone	4
Severe	2
Osteomyelitis, which responded to treatment	2
Osteomyelitis, which did not respond to treatment and eventually came to amputation	1

Malignant Growth

Development of a carcinoma at the site of fracture, involving the tibia and necessitating amputation... 1 case

Amputations (Total, 3 Cases)

1. Immediate, due to the marked loss of soft structures and bone
2. Late, for chronic osteomyelitis and a hopelessly functionless extremity
3. Late, for carcinoma of the leg

Deaths (Total, 8 Cases)

Death without the patient reacting from shock (In all 3 cases there were multiple injuries.)	3
Death twenty-four hours after admission and following operation for ruptured spleen	1
Death five weeks after accident (No autopsy was obtained; patient apparently died from a pulmonary embolus.)	1
Death from fulminating infections (In both cases the infections were due to mixed staphylococci and streptococci.)	2
Death following amputation for infection of compound fracture	1

CONCLUSIONS

A compound fracture is an emergency and requires immediate treatment.

The treatment must be directed toward the care of first the patient and then the part.

In the prevention of infection, more is to be expected from proper washing than from the so-called antiseptics.

Immediate splintage or traction allays pain, lessens the danger of shock and avoids further trauma.

A plea is made for the immediate, careful and expert handling of compound fractures.

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A REVIEW OF UROLOGIC SURGERY

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KIDNEY

Tumor.—Droschl [1] reviewed the results of treatment in 66 cases of tumor (hypernephroid) of the kidney from the surgical clinic at Graz, Austria. He described in detail the symptoms, diagnosis and treatment. The treatment was always surgical. The results were poor. He agreed with the statement of Wildbolz that three years after the operation only a third of the patients with such a tumor are still alive. Droschl expressed the opinion that hypernephroid tumor is of a higher grade of malignancy than carcinoma or sarcoma.

Delon [2] reviewed the embryology of the kidney and the various hypotheses that have been advanced concerning the pathogenesis of renal tumor in children. These hypotheses fall into three groups, namely: (1) that such a tumor in children is of embryonal origin, (2) that it is caused by various inclusions, such as the wolffian body, myotoma and mesoderm, and (3) that it results from an "illegal union" between the metanephros

1. Droschl, Hans: Ergebnisse der Behandlung von hypernephroiden Tumoren, Ztschr. f. urol. Chir. u. Gynäk. **42**:206-221 (May) 1936.

2. Delon, Jeanne: Tumeurs malignes du rein chez l'enfant: Etude anatomo-clinique, Arch. d. mal. d. reins **9**:655-692 (Nov.) 1936.

and the adjacent tissues. When a section taken from the peripheral region of the fetal kidney is compared with a section from a tumor, the similarity is striking. In both cases undifferentiated cells are seen in the process of transformation into connective tissue and epithelial cells. In the fetal kidney this transformation is perfect and regular; the epithelial cells become arranged in renal buttons, secretory tubules and glomeruli, whereas the connective tissue cells form the interstitial tissue. In the renal tumor this transformation remains incomplete and becomes clearly malignant. The epithelial cells proliferate much more actively than in the normal kidney. They reveal abnormal mitosis, and their structural evolution remains imperfect. They may be in masses without any apparent order, or they may be arranged like the renal buttons of the embryonic kidney; the formation of tubules is rare, and these, when present, are definitely neoplastic and are not confined to a single basal layer but possess several layers of cells and seldom present a central lumen. Glomeruli are altogether exceptional. The connective tissue cells also proliferate more actively than in the normal kidney and are characterized by various anomalies. They show various stages in the evolution of adult fibroblasts and a tendency to form collagen. This is never present in any significant amount in the normal kidney.

These epithelial and connective tissue modifications are the essential factor in the renal tumor in childhood. They are very simply explained on an embryologic basis. The tumor is the malignant degeneration of the nephrogenic tissue. Smooth muscle fibers are occasionally observed. In the normal kidney these are found in the hilar region; they extend into the ureter and sometimes even become insinuated between the lobes of the kidney; they also exist beneath the renal capsule. Hence their presence in a tumor should not occasion any astonishment and is as logical as the presence of epithelial or connective tissues. Cartilage and bone are rarely present, but when present they always appear in the middle of dense connective tissue abounding in collagen. As is well known, these are classified as connective tissues, and their presence is very simply explained by metaplasia. The interpretation of striped muscle fibers is certainly more difficult. Only once has the author found these, and then they were mingled with undifferentiated cells and fibroblasts, from the former of which they appear to be derived. The theory of inclusions and of "illegal union" is rejected by Delon, and the embryonal theory of Maus and Busse is accepted without reservation. The terms "malignant dysembryoma" and "malignant embryonal nephroma" seem to her the best designations.

In considering the genesis of the kidney, it has been pointed out that the development of the secretory portion does not take place when the ureteral bud is imperfect or when there is any arrest or modifi-

cation in the migration of the germinal cells. When such an arrest of development occurs, it gives rise to a malformation, but it does not explain a neoplasm. Some authors think, however, that the malformation causes malignant degeneration; but one could just as easily hold that it is malignant degeneration that causes an arrest of development. These are only hypotheses, which can neither be affirmed nor denied at present. The ultimate cause of malignant tumor of the kidney in children, like that of all forms of carcinoma, still eludes investigators.

Anomalies.—Everett [3] reported in detail a case of complete unilateral reduplication of the renal pelvis and ureter. The symptoms, complicating pathologic changes and treatment in 48 other cases presenting similar anomalies were tabulated and discussed. A special study of the differential function of the various renal segments was made, and the conclusion was drawn that in the absence of serious complicating pathologic lesions the function of the two kidneys is usually about equal; on the side on which the reduplicated organs are present the function of the lower segment usually exceeds that of the upper segment in the ratio of about 2:1. Attention is called to the value of ureteral dilation as a conservative measure in the treatment of persons in whom pathologic changes have developed and to its possible rôle in the reduction of the incidence of operative treatment.

Stone.—Randall [4] reviewed the five theories which are current today as reasons why a kidney becomes encumbered with a calculus and at the same time pointed out the close relationship of these theories.

Priority belongs to the dietary theory. Attention is called to this causal factor from two separate angles. First, and perhaps of the greatest importance, is the realization that the occurrence of vesical stone in childhood has almost disappeared. In former years stone in the urinary tract of children was common. Now it is rare, and the only factor which can be pointed out as bearing on the disappearance of this surgical condition has been a liberalization of the diet of children. Children today are fed from infancy a diet which would have made our grandparents shudder. The second point under this theory has been the proof that diets deficient in vitamin A are exceedingly prolific in the formation of calculus. The reason given is that such a diet causes certain changes in the epithelium of the urinary tract, which is termed keratinization. Two factors are significant: first, that such stones are consistently formed of calcium and magnesium phosphates, and second,

3. Everett, H. S.: Reduplication of the Renal Pelvis and Ureter, J. Urol. **36**:1-21 (July) 1936.

4. Randall, Alexander: An Hypothesis for the Origin of Renal Calculus, Tr. New England Branch Am. Urol. A., 1935, pt. 3, pp. 6-22; New England J. Med. **214**:234 (Feb. 6) 1936.

that in experimental animals in which stone has been so produced such concretions have been made to disappear if the diet is changed to one rich in vitamin A.

The second theory which enters this picture is that of infection. Again, two factors are of great significance as regards infection and stone: first, the concomitant frequency of infection when epithelial changes due to deficiency of vitamin A predominate, with the interrelationship of these two theories; and second, the part that infection frequently plays as an etiologic factor in the recurrence of renal stone.

The third theory concerns the effect of stasis and faulty drainage. Long recognized factors in the formation of stone in the lower part of the urinary tract, stasis and faulty drainage must likewise play a definite part in the etiology of certain stones in the upper part of the urinary tract. Stone has been found in a relatively high percentage of patients who have been bedridden because of generalized disease, immobilization for fractured bones and tuberculous lesions of the hip and spine.

The fourth theory is one of disturbance in the colloidal mechanism of the urine, which plays an important part in the body's normal ability to eliminate insoluble crystalloids in a supersaturated solution in the urine.

The fifth theory is of recent origin; in this, it has been pointed out that hyperplastic disease of the parathyroid glands is responsible for decalcification of the bony skeleton and the occurrence of an actual calcium diabetes in the urine.

Kimbrough [5] stated that all calculi of the urogenital tract should be removed as soon as the condition of the patient will warrant. There are no silent stones, and delay in removal is always dangerous. The type of operation that will cause the minimal amount of renal injury should be employed. Posterior pelviolithotomy is the operation of choice unless conditions make other procedures advisable. Repeated attempts at removal of ureteral calculi by manipulation may become a hazardous procedure, and persistence in this method of treatment is not commendable. Operation for ureteral calculi rarely causes morbidity. Drainage by means of nephrostomy has given good results when stones were present in association with severe renal infection, hydronephrosis and ureteral obstruction. The gastro-intestinal symptoms of urinary calculus merit important consideration. Each case in which stones are bilateral must be considered on its own merits; no fixed rule can be followed. The side on which the most acute symptoms are present or which reveals evidence of obstruction usually should be operated on

5. Kimbrough, J. C.: The Treatment of Urinary Lithiasis, J. Urol. **36**:57-70 (July) 1936.

first. Other things being equal, the first operation should be done on the better kidney. If a patient has both renal and ureteral calculi, it is advisable to remove the ureteral stones before operating on the kidney. In the treatment of calculus of the urogenital tract, the high incidence of recurrence makes the conservation of renal tissue imperative. Nephrectomy should be performed only as the last resort. Renal sympathectomy is an important procedure in the operative treatment. The removal of the calculus is only a phase in the treatment of urinary lithiasis. Adequate postoperative care is necessary to reduce the incidence of recurrence and to prevent morbidity.

Higgins [6] reported that he secured the following results by the use of the acid ash diet high in vitamin A in the treatment of urinary calculi.

In his series of 23 cases in which stones were too large to pass spontaneously from the kidney, the diet brought complete solution, as indicated by roentgenographic studies and by pyelography.

In another group of 17 patients calculi were passed at frequent intervals. After the acid ash diet high in vitamin A had been followed, all the patients were entirely free from symptoms for more than two years.

During the past two and a half years there was only 1 instance of recurrent formation of stone after operative removal of stones from the upper part of the urinary tract. This patient did not follow the routine that was outlined for him. Higgins does not wish to infer that, postoperatively, only the acid ash diet high in vitamin A was used. This was prescribed in addition to other therapeutic measures that he always has used, such as eradication of infection and elimination of stasis. Since this regimen has been followed, the incidence of recurrent formation of stone has been reduced from 16.4 to 4.7 per cent in his cases.

He also has studied a series of cases in which the stones have diminished in size, but insufficient time has elapsed to expect their complete solution.

In other cases he has been unable as yet to note any decrease in the size of the calculi, although the patients have followed the diet for a period of from four to five months. He stated that it was impossible to determine whether a noticeable decrease in the size of stones will occur after the diet has been followed for longer periods. He does believe, however, that if the stone is not producing definite renal injury and is not disabling the patient from pain, conservative treatment should be attempted.

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6. Higgins, C. C.: Experimental and Clinical Observations on Urinary Calculi, Tr. New England Branch Am. Urol. A., 1935, pt. 2, pp. 6-17; New England J. Med. **213**:1007 (Nov. 21) 1935.

He is certain that if in addition to the other therapeutic measures which have been used previously a carefully planned diet is prescribed to which vitamin A is added postoperatively, the recurrent formation of stones can be reduced to a minimum.

Higgins [7] stated that recurrent renal lithiasis, or the formation of a calculus after complete removal of the original stone, may be classed as a true recurrence and the persistence of stones or fragments of calculi which were overlooked at operation, as a false recurrence. Whether the type of stone is single or multiple, soft or hard, influences the tendency to recurrence. In Higgins' series of cases of renal calculi, those which were soft recurred more frequently. This may have been due to the retention of small fragments of sand in the kidney which acted as a nucleus for the further formation of stone. The postoperative results when bilateral calculi are present are not satisfactory from the point of view of recurrence. Bilateral infection of the urinary tract is present in a large percentage of cases, and this persists after operation. Recurrence usually follows the removal of bilateral calculi.

In recent years there has been a progressive tendency toward conservatism in operations for renal conditions. Pelviolithotomy was used in more than 74 per cent of Higgins' cases and is the procedure of choice for the removal of calculi from the renal pelvis, except when more extensive operation is required. Since trauma is minimized, recurrences seem less likely than when more extensive procedures are required. Nephrolithotomy may be necessary when a calculus is branched or is confined to a calix associated with a narrow infundibulum. This method should always be as conservative as possible, and often a small incision over the dilated calix is sufficient. Heminephrectomy may be indicated in the presence of marked dilatation of a calix in which severe infection is localized at the site of the stone. Nephropelviolithotomy may occasionally be required when technical difficulties arise or when drainage with a nephrotomy tube is desired. When this is used, the finger in the pelvis serves as a guide for the accurate placing of the tube.

In considering the postoperative management of the patient from whom a calculus has been removed by surgical intervention, various factors associated with the formation of stone must be considered. Infection may be divided into the focal type and that confined to the genito-urinary tract. When infection is present in the genito-urinary tract, a complete study of the causative organism is required, and it should be ascertained whether it has the urea-splitting property. If a colon bacillus or a mild staphylococcic infection is present in the kidney, conservative treatment with urinary antiseptics, such as ammonium

7. Higgins, C. C.: Prevention of Recurrent Renal Calculi, J Urol. **35**:494-498 (May) 1936.

chloride and methenamine, should be employed. If, however, the infection cannot be eradicated by this procedure, a ketogenic diet should be used. Urostasis also seems to be associated with the recurrent formation of lithiasis. If stasis is present, it must be eliminated by dilation of the ureters or other required procedures. Higgins expressed the belief that vitamin A should be prescribed postoperatively to overcome any deficiency in this vitamin and because of its specific effect on the epithelial structures. In a few cases in which microscopic examination was made of a small piece of the pelvis of the kidney adjacent to a calculus, complete loss of epithelium has been found, which probably was caused by constant trauma by the calculus, and small accumulations of sand were found to be adherent at this point. Later, the calculus may become enlarged and then pass spontaneously down the ureter or fall into the dependent lower calix, affording a nucleus for further development of the stone. Because of the healing effect of vitamin A on the epithelium, this vitamin therefore is of value in promoting more rapid epithelization at the sites where the denudation has occurred. In a recent series of 43 cases of renal lithiasis, Jeans' test for deficiency of vitamin A was positive in 52 per cent. The relationship between hyperparathyroidism and renal lithiasis must also be considered. If hyperparathyroidism is present, exploration of the parathyroid glands is indicated, and the removal of a tumor of this gland will prevent recurrence of the calculi which were due to hyperparathyroidism. In view of the experimental evidence, Higgins expressed the belief that the recurrent formation of calculi could be minimized by the use of dietary treatment in addition to the other therapeutic procedures that have been used postoperatively in the past. The patient with calculi which are composed of calcium and magnesium phosphates, or carbonates, which form in an alkaline urine, or oxalates, which are precipitated in a wide range of urinary reactions, should be placed on an acid ash diet high in vitamin A after operation, thus shifting the urinary reaction to the acid side. When the calculi are composed of cystine or uric acid, the p_H should be shifted to the alkaline side by the use of an alkaline ash diet high in vitamin A after it is ascertained that phosphates and carbonate are not being precipitated at that degree of alkalinity. Vitamin A should be given in the form of capsules of halibut liver oil or carotene in oil, and Jeans' test should be rechecked to make certain that adequate amounts have been prescribed. In Higgins' experience, recurrent calculi are composed chiefly of calcium and magnesium phosphates, carbonates and traces of oxalates. These calculi form in an alkaline urine, and by shifting the reaction of the urine to the acid side, their recurrence should be minimized. Since the dietary regimen has been added to the postoperative treatment, the incidence of recurrent

renal lithiasis has been reduced from 16.4 to 4.7 per cent during the past three years.

Hydronephrosis.—Henninger and Sitka [8] confirmed the experiments of Enderlen and others that urine from the hydronephrotic kidney is less toxic than normal urine. In a series of experiments they removed both kidneys of rabbits and found that the rabbits died from fifty to eighty hours later. Rabbits lived twice as long when both ureters were tied and the kidneys were left intact. To prove the toxicity of normal urine, they opened the ureter in the retroperitoneal space of 10 rabbits. Three animals died from fifty to one hundred hours later. A space filled with urine was found beside the normal kidneys. Seven animals survived the operation and were killed later. It was found that the opening in the ureter had closed and that hydronephrosis had formed above.

When the ureter had been ligated before being cut, so that hydronephrosis developed, the rabbits survived the operation, even when the incision in the ureter was kept open by a drain. This suggests that although normal urine usually kills a rabbit by resorption, urine from a nephrotic kidney never does.

The authors found the same adhesive tendency in the bladder that they had found in the course of their experiments on the ureter. When half of the bladder had been resected and left open to the peritoneum, it was closed in a few hours by the intestines, before peritonitis developed. The rabbits always survived the operation, and the bladder went on functioning normally.

Berkman [9] drew attention to a group of patients who have hydronephrosis that is often unrecognized or misdiagnosed. These patients complain of attacks of pain in the upper part of the abdomen on one side or the other. Urinalysis, studies of renal function and a plain roentgenogram of the urinary tract reveal nothing abnormal. An important clinical clue in the detection of the hydronephrosis is obtained by determining the relationship of the pain to the posture of the patient. Pain occurs most frequently after exercise or toward the end of the day, when the patient has been erect for some time. Considerable relief is usually obtained by lying down, on the back, on the affected side or on the unaffected side. When such a history is elicited, one's suspicion of the possibility of hydronephrosis should be aroused, especially

8. Henninger, H., and Sitka, B.: Experimentelle Untersuchungen über die Toxicität des normalen und Hypdronephrosenharnes bei Kaninchen und Mitteilung von Befunden einer merkwürdigen Verklebungstendenz innerhalb des Kaninchenharntraktes, Ztschr. f. urol. Chir. u. Gynäk. **42**:101-114 (Feb.) 1936.

9. Berkman, J. M.: Further Observations on the "Position-Relief Syndrome" in Hydronephrosis, Proc. Staff Meet., Mayo Clin. **11**:331-333 (May 20) 1936.

when examinations of other organs give negative results. Intravenous urography usually reveals the true diagnosis if renal function is not too seriously impaired. Surgical treatment is then generally indicated, and this usually consists of a conservative type of operation on the kidney, pelvis or upper portion of the ureter.

Trauma.—Dósza [10] reported 83 cases of injury to the kidneys, in 67 of which the trauma was the result of direct violence. Hematuria was present in 65 patients. Conservative treatment was satisfactory for 79, and operation was performed on 3. One patient, who came to the clinic five days after the injury, died before operation could be performed.

Twenty-seven patients were seen from six months to thirty years after the initial injury and had to be operated on for various consequences of the renal injury. Hydronephrosis was present in 6, renal stones in 9, tuberculosis of the kidney in 10 and renal tumors in 2.

In some cases no association with the injury was demonstrable. In 2 cases the tumors were present before the accident. In several cases in which stones were present the connection could not be proved but was probable.

In cases of tuberculosis there are two possibilities which may arise after injury to the kidney: (1) The injury may make a preexistent tuberculous infection more obvious, and (2) it can send tubercle bacilli from distant infected areas to the injured kidney, which after the injury has a lowered resistance.

Dósza found that nephritis developed following an accident in 2 cases. He believed that in those cases the accident was really the principal etiologic factor and that the diagnosis was traumatic nephritis.

Findlay [11] stated that the mortality from rupture of the kidney continues to be high, and the lesion too frequently escapes prompt diagnosis. Not only is the injury to the kidney serious in itself, but it is frequently accompanied by other injuries of the thorax and abdomen, which require the best surgical judgment. Slight bleeding from the kidney may result from mild indirect trauma, such as a blow on the buttocks or a fall; actual rupture of the kidney is usually attributable to a direct blow over the kidney itself. Rupture caused by direct violence may be due to a rapid impact or to slow compression, the kidney being forced against the vertebral column or lower ribs. Mild trauma may result only in bruising of the kidney, with slight swelling and extravasation of blood. In true rupture of the kidney there are numer-

10. Dósza, Eugen: Ueber die subcutanen Nierenverletzungen und deren Spätfolgen, Ztschr. f. urol. Chir. u. Gynäk. **42**:222-230 (May) 1936.

11. Findlay, F. M.: The Treatment of Ruptured Kidney, with Case Report, West. J. Surg. **44**:117-121 (Feb.) 1936.

ous fissures which vary in extent and depth. If the pelvis of the kidney is involved, urine escapes into the surrounding tissues. If the renal artery or vein or one of their major branches is torn across, there is a prompt hemorrhage, with formation of a retroperitoneal tumor, a drop in blood pressure, pallor and all of the typical symptoms of shock. More frequently the injury consists of transverse rupture of the cortex, with the escape of blood but of only a small amount of urine into the surrounding tissues. Extravasation of a small amount of sterile urine rarely causes sepsis.

A problem of diagnosis arises when the kidney is known to be ruptured and the patient also has multiple injuries. The more common injuries are fracture of the ribs with pleural effusion, rupture of the spleen or liver and perforation of the intestine.

Analysis of the reported deaths in any series of injuries to the kidney reveals that surgical shock is the most common cause of death. Hemorrhage is one of the main causes of surgical shock.

Infection.—Von Illyés [12] reviewed the subject of suppuration of the renal parenchyma without taking into consideration the etiology, the diseases or the anatomic alterations which may have preceded the formation of pus. All forms of suppurative inflammation which have been caused by pyogenous bacteria are considered, with the exception of tuberculosis. All suppurations of the kidney that originate from general or local infections transmitted by the hematogenous or the lymphogenous route and infections following urinary diseases or arising from anatomic changes are also considered.

With regard to the pathogenesis, and from a point of view of systematic classification, von Illyés expressed the belief that it is simplest to suppose that the infections are of the following types: hematogenous, or descending; urogenous, or ascending, and lymphogenous. It is known that often neither surgical exploration nor postmortem examination will inform the physician how the infection has started; so the condition cannot be classified.

In hematogenous infection the capillary blood vessels of the glomeruli are obstructed by the bacteria invading the renal blood vessels, and local suppuration sets in. In other cases single germs permeate the canaliculi, reaching the medullary substance where they provoke abscesses.

Concerning excretion or metastatic abscesses, a larger number of germs or necrotic small particles of tissue may obstruct larger vessels, thus causing an infarct, which may decay through infection.

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12. von Illyés, Géza: Ueber die Eiterungen des Nierenparenchyms, Kong. internat. Gesellsch. f. Urol., 1936, pp. 246-286.

In urogenous infection the lower part of the urinary tract is usually already infected. From there, infection ascends to the kidney, where urinary retention favors the development of infection. Bacteria reach the parenchyma by an antiperistaltic movement of the ureters or reaches the pelvis of the kidney by vesico-ureteral reflux; from thence they enter the kidney. By pyelovenous or pyelotubular reflux, more frequently even by pyelo-interstitial reflux, they travel as far as under the capsule or into the cortical substance, where they create small, purulent foci. Small interstitial abscesses such as these may break into the canaliculi, from whence they reach the medullary substance, presenting the same picture as if hematogenous infection, passing from the glomeruli into the canaliculi, had taken place. As the pelvis is always affected in such cases, this kind of inflammation is called pyelonephritis.

The lymphogenous etiology of renal infection can be ascertained in rare cases only. The infection following appendicitis or infections of the female adnexa may reach the kidney by way of the lymphatics in the walls of the ureter. Colon bacilli are the organisms most frequently found, but staphylococci and streptococci and other pyogenous germs also are found.

Clinically, three types of infection are distinguished: (1) suppurative nephritis, consisting of (*a*) circumscribed or scattered minor or major abscesses and (*b*) abscess of the kidney; (2) suppurative pyelonephritis, and (3) pyonephrosis, or shrinking kidney.

The hematogenous (descending) less often the urogenous (ascending) renal suppurations belong to the first group. These reveal minor or major, scattered or circumscribed and cortical or medullary abscesses. A special form of hematogenous infection, the carbuncle of the kidney, is included by von Illyés in this group. The term nephritis indicates mainly hematogenous renal suppurations. The second group is the largest and includes the various suppurations, mostly urogenous, that follow urinary diseases of different kinds. The term pyelonephritis indicates the origin from the pelvis or the urogenous (ascending) pathway of infection. The third group includes all the final results of suppurations. In this group the kidney is already destroyed but still causes symptoms that necessitate surgical intervention.

Cabot [13] considered blood-borne infections of the kidney, chiefly those produced by the pus-producing cocci. For many years it has been known that various forms of these cocci may be found in the otherwise normal urine of patients who have peripheral infections, such as boils, carbuncles, septic wounds and acute infections of the upper part of the respiratory tract. In order to study the latter point more closely, a series

13. Cabot, Hugh: Blood Stream Infections of the Kidney, Brit. J. Urol. **8**:233-256 (Sept.) 1936.

of 46 patients suffering from acute inflammatory processes about the mouth, throat and ear were studied. The group was selected from among patients who had a urine normal to ordinary tests and some fever, but revealed no signs or symptoms suggesting an infection of the kidney. The urine was carefully obtained, always by catheter from the females. It was studied by smear and culture, the smear being made from urine centrifugated for a considerable period at high speed. Of these 46 cases, organisms from 32 were revealed in the smear and from 18 in the culture.

It is important to note that the pus-producing cocci appear in the urine early in the disease, but disappear as a rule in a few days, although occasionally they may persist for several weeks in an otherwise normal urine.

The lesions are primarily cortical or medullary. They tend to coalesce with the production of a massive abscess and usually show early and marked perinephritis, often developing into a perinephritic abscess.

Besides the classic methods of diagnosis, stress is laid on the value of roentgenography in the diagnosis in these cases. In cases of perinephritic abscess clouding or obliteration of the shadow of the psoas muscle is generally revealed by modern methods of roentgenography. Scoliosis is not rare but is a rather late sign. Limitation of motion of the diaphragm on the infected side, as studied by the fluoroscope, is more important than the literature would suggest. Particular emphasis is laid on the value of pyelography, both by the excretory and by the retrograde method. This will give precise information as to the development of massive abscess by revealing deformities of the calices. It will also be of much value in showing displacement of the kidney by a perinephritic abscess, sometimes at an early period. Stress is laid on the value of limitation of the normal mobility of the kidney caused by the early development of perinephritis, often in the absence of a perinephritic abscess. A series of observations is reported, showing diminished visualization of the infected kidney as seen in the excretory urogram.

For the purposes of treatment, the infections are divided into four groups.

1. Fulminating infection. Operation is believed to be the only available method of treatment for this type.

2. Acute infection, the condition being characterized by chills, high fever, leukocytosis and costomuscular tenderness in association with a normal urine, except for the practically universal presence of cocci obtained by staining the sediment after prolonged centrifugation at high speed. For this type of infection operation has been generally

regarded as almost invariably necessary. Cabot was not in agreement with this opinion and expressed the belief that in a majority of cases recovery will take place if the patient is treated medically. A position of "armed watchfulness" should always be maintained, the reaction of the patient to the disease being carefully observed, particularly with regard to the tendency of the pulse to become more rapid and of anemia to develop. Coupled with this should be frequent observations of the conformation of the renal pelvis both by the excretory urogram and by the retrograde pyelogram. This will enable massive abscess and perinephritic abscess to be discovered early.

3. Subacute infection, the picture being less stormy, but presenting clear evidence of a lesion of the kidney. For this type of infection operation is not indicated, except when perinephritic abscess develops.

4. Infections of the borderline type which occur not rarely as a complication of infections of the upper respiratory passages, the diagnosis being made only on the basis of a slight costomuscular tenderness, the presence of fever which is not satisfactorily accounted for by the conditions in the throat and by the finding of cocci in the urine, as previously described. For this type of infection operation is practically never necessary, since perinephritic abscess is uncommon.

Cabot gave the following indications for operation: (1) the fulminating type of infection; (2) the widespread infection of the kidney in which the patient seems unable to control the disease, as may be noted by the development of anemia and failing general condition; (3) massive abscess of the kidney, as shown by the pyelogram, and (4) perinephritic abscess.

The following types of operation are indicated: (1) nephrectomy for the fulminating infections; (2) nephrectomy for widespread infection, but when massive abscess is not present and the patient is losing ground; (3) decapsulation and drainage for the well localized massive abscess, and (4) exploration for the perinephritic abscess. The precise operation for the perinephritic abscess is determined by the following factors: (*a*) If the pyelogram shows no evidence of massive abscess or evidence of deformity of the pelvis, simple drainage is employed. (*b*) If there is perinephritic abscess and evidence of massive abscess, the perinephritic abscess must be drained and the kidney explored in the region indicated by the pyelogram. (*c*) For perinephritic abscess of long standing, even with evidence of destruction of renal tissue, as shown by the pyelogram, drainage of the perinephritic abscess alone is indicated in the first instance. Many of the patients will then recover, since the massive destruction of the kidney has already drained into the perinephric space. It is not wise to uncover the kidney widely in these cases, since extensive dissection will be necessary with the break-

ing down of well established barriers. If the perinephritic abscess has been drained, and the wound fails to heal or after healing reopens, further exploration can be safely undertaken.

Necker [14] stated that suppuration of the parenchyma, in a wider meaning of the term, is the pathologic result of all nonspecific renal infections. He reviewed abscess-like suppurations of the kidney and divided them into two groups. The first group included all forms of suppuration limited to the parenchyma itself, namely, primary suppurations of the parenchyma. These forms of suppuration are still insufficiently studied and diagnosed with difficulty only; therefore, mainly the first group will be considered. The second group of suppurations is easier to diagnose clinically and is more frequently found; namely, secondary pyelonephritic or pyelorenal suppurations of the parenchyma in which the urinary excretory pathways are always involved.

Primary suppuration of the parenchyma is seldom diffuse; more often it is a sharply circumscribed disease of the cortex of the kidney. The organisms are pyogenous cocci and Staphylococcus aureus but rarely streptococci. The infection usually starts from suppurative foci in the peripheral zone. The morphology and the extension of the focus of infection depend on the quantity and the virulence of the invading bacteria. Forms of clinical importance are: the rare, diffuse miliary abscess and infarction of the kidney, the grouped miliary abscess, the tumor-like, boil-like cortical suppuration, the large intrarenal abscess and the xantholipomatous staphylomycosis.

The participation of the cortical layers of the kidney in all forms of suppuration of the cortex proves the connection of the cortex with its coverings. It is impossible to distinguish clinically diseases of the adipose capsule, such as epinephritic abscess or fibrosclerotic epinephritis, from suppurations of the cortex, for frequently the former are manifested only by the latter.

Secondary suppuration of the parenchyma is usually caused by infection with colon bacillus. The infection spreads, also in cases of hematogenous infection, by ascending from the pelvis toward the cortex, after having gone through three phases: the issue of the bacteria out of the blood, their adherence to the renal parenchyma and their multiplication. This development is influenced by dynamic factors of the urinary ways (impediments or obstacles to the outflow). In case of infection by cocci, suppuration of the parenchyma is the primary condition of the diseased kidney, whereas in case of infection by colon bacillus, it is the final stage of the dissemination of the infection.

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14. Necker, Friedrich: Parenchymeiterungen der Niere, Kong. internat. Gesellsch. f. Urol., 1936, pp. 299-358.

Intravenous and retrograde pyelography enables an accurate diagnosis to be made of the boil-like suppurations when the disease has provoked elongation and dislocation of the calices. The picture is similar to that of other strangulating processes, such as tumors, cysts or polycystic degeneration. In spite of the progress of the methods of examination, a diagnosis of cortical suppuration of the parenchyma can be based, after elimination of other possible disease, only on the septicopyemic aspect, the painfulness on pressure in the lumbar region and on the temperature. At present, a clinical classification of the various types of cortical suppurations of the parenchyma is not possible.

Therapeutically, the following rules can be established: Considering that primary cortical suppuration heals spontaneously by breaking into the urinary tract, by absorption or by cicatrization, a short period of observation and conservative treatment are always justified.

Conservative treatment should not be delayed. An early diagnosis and early exploratory operation and decapsulation are desirable before the adipose tissue is destroyed by suppurative processes and before surgical intervention is made difficult by fibrosclerotic alterations of the renal capsule. If diagnosed early, most of the cortical suppurations give gratifying results with conservative operative treatment. Decapsulation, incision or enucleation of the focus of disease, with subsequent antiseptic open treatment, will usually give good results.

In secondary suppuration of the parenchyma there are satisfactory diagnostic methods of securing accurate information as to the etiology and bacteriology and the function of both kidneys and their motor function. In many cases conservation of the kidney is prevented by the etiology of the disease (operative lesions of the ureters, after gynecological operations, extirpation of diverticula and resection of the bladder). In other cases treatment with an inlying catheter, cystotomy or permanent drainage of the ureter may sometimes cause improvement, even if the condition is very serious. Often complete failure of the latter measures to reduce the fever enables the diagnosis of isolated suppurative foci to be made. In such cases the kidney can be saved only rarely from total destruction by decortication, ureterolysis, incision of abscesses or temporary nephrostomy. If the functional condition of the second organ is satisfactory, nephrectomy alone is sometimes indicated.

Beer [15] reviewed 61 cases of coccic infection of the renal cortex observed prior to 1926 and 43 more recent cases in which operation was performed. Men are more frequently affected than women, and the majority of patients are between the ages of 20 and 50. In 38 of 43 cases, Staph. aureus was noted in cultures of pus; in 3 cases there

15. Beer, Edwin: Coccic Infections of the Renal Cortex, J. A. M. A. **106**: 1063-1070 (March 28) 1936.

was mixed infection. In 32 cases there were perinephritis and perinephritic abscesses as well as cortical abscesses. In 9 cases the kidney was not exposed or visualized, according to the records. In 13 cases the cortical abscess was anterenal. A study of the blood cultures revealed staphylococcemia in 7 of the 26 cases studied in this manner.

As the features of the disease may vary from an acute fulminating process to that of a subacute or chronic septic condition, the clinical picture presented by this type of infection may be said to be protean in character. In the majority of cases the picture is typical and may easily be recognized. While the focus of pus is under the fibrous capsule of the kidney and therefore under tension, the symptoms may be marked. As the cortical abscess ruptures into the perinephrium and localizes in this fatty tissue, symptoms may subside temporarily, only to become more definite as tension develops in the perinephric space. When the perinephric abscess breaks through the fascia of Gerota, tension disappears and many of the symptoms temporarily abate. As pus ruptures downward and descends between the two leaves of Gerota's fascia toward the pelvis, the symptoms may subside until the reaction of the tissues encloses the accumulation of purulent material.

The disease is characterized by a rise in temperature with or without chills and with pain in one or both lumbar regions. On physical examination the kidney usually cannot be felt, but if palpable it may be movable. There is regularly a definite tenderness over the involved kidney. If the elevation of temperature continues, there is a continued loss of weight and progressive anemia. The patient appears to be suffering from septicemia. Leukocytosis is usually present while the patient has fever. Examination of the urine at this stage may reveal nothing of significance.

The clinical picture of the typical, acute condition, whether associated with bacteremia or not, should be recognized and surgical treatment by incision, drainage and decapsulation in situ should be carried out. If this is done, the wound should not be closed tightly, as it is likely to become infected from the staphylococcic pus. Adequate rubber dam in front and behind the decapsulated kidney should be left in place for drainage. Usually, if the abscess is thoroughly drained and does not involve the whole kidney, decapsulation is curative.

Tuberculosis.—Wildbolz [16] stated that until recently it has been generally recognized that renal tuberculosis heals in only exceptionally rare instances. The studies of Medlar differ from this earlier opinion. He found areas of tuberculosis in the kidneys of patients who had died of pulmonary tuberculosis. These areas were mostly cicatrized and had

16. Wildbolz, Hans: Ueber die Möglichkeit einer Spontanheilung der Nierentuberkulose, Ztschr. f. urol. Chir. u. Gynäk. **42**:257-267 (Aug.) 1936.

never caused symptoms during life. Clinical observations seemed to confirm Medlar's opinion that renal tuberculosis may heal in the early stages.

There has been considerable confusion in the American and European literature concerning renal tuberculosis. This is due mostly to the fact that the nomenclature in the different countries varies considerably. What is described as "the early stages of renal tuberculosis" in America is called by European authors "tuberculous nephritis," and the fibrous type is spoken of as indurative tuberculosis. Beginning caseation, even if it is slight, is spoken of as "caseate renal tuberculosis" in the United States, and it is judged incurable without operation. Considering the difference of nomenclature, there is no difference in the opinion of most American and European authors.

In the treatment of renal tuberculosis, Wildbolz agrees with American surgeons. He does not advise nephrectomy in cases of tuberculous nephritis. In 1,300 cases of renal tuberculosis in which the examination was made by Wildbolz, there were only 20 of this type. In 17 cases the kidney had to be removed later, and at this time caseous tuberculosis was found. In only 3 of the 1,300 cases did the tuberculosis appear to be healed without operation. A detailed description is given of 1 case of spontaneously healed renal tuberculosis in which necropsy was performed. This is the second case of this type described in the literature.

Wildbolz concluded that the new communications on the possibility of a spontaneous healing of renal tuberculosis do not permit a change in the indications on the operative treatment of this condition. Caseous renal tuberculosis practically never heals without operative intervention. Noncaseous renal tuberculosis appears to have some chance of healing without operation. These forms are difficult to distinguish from the caseous forms, although the triad of symptoms, namely, bacilluria, pyuria and lessened function of the kidney, strongly suggests the existence of caseous tuberculosis. Therefore, in Wildbolz' opinion, a unilateral occurrence of this group of symptoms is sufficient evidence to remove the infected kidney if the opposite kidney is functioning well. The diagnosis of noncaseous tuberculosis is permitted after a kidney excreting tubercle bacilli reveals no marked impairment of function and its urine does not contain pus cells. The possibility of a nonoperative cure exists in such cases, and an attempt in nonoperative treatment may be made, even though the infection is one sided. The patient with such an infection must remain under continuous observation. Nephrectomy will become urgent if marked impairment of function or pyuria is found in a kidney which has been excreting tubercle bacilli, or if even a small cavity is seen in the pyelogram.

Wyler [17] reported the results of an experimental study on tuberculous bacilluria. After injection of a thin suspension of tuberculous bacilli (bovine type) into the renal artery of rabbits, the urine was examined continuously for three days. It was impossible to find tuberculous bacilli either in direct examination or by injection into a guinea-pig. Intravenous injection of dextrose causes polyuria. A suspension of tuberculous bacilli injected with the dextrose does not cause bacilluria.

Actinomycosis.—Kretschmer and Hibbs [18] reported a case of actinomycosis of the kidney of a girl aged 10 years. A review of the literature revealed that only 3 cases of the disease have occurred in children.

Renal actinomycosis is probably never primary in the kidney. The persistence of a sinus after nephrectomy for a chronic suppurative process in the kidney, in which tuberculosis of the kidney has been ruled out, should make one suspect that the condition may be due to actinomycosis. Likewise, the presence of a persistent discharging sinus in other parts of the body should lead one to suspect that the renal lesion may be due to actinomycosis.

Cystic Disease.—Wells [19] reported 2 cases of unilateral polycystic disease of the kidney and summarized the present conception of the etiology, pathology, diagnosis and treatment of polycystic kidney. The first patient was a man aged 40 who complained of renal colic on the left side. Retrograde pyelograms gave evidence of the typical changes of polycystic disease on the left and a normal right kidney. At operation on the left kidney the peritoneum was opened, and a normal right kidney was palpated. The left kidney was removed, and in addition to polycystic changes a large intracystic papilloma was found.

The second patient was a woman aged 22; an enlarged left kidney was found on general examination. Pyelograms revealed a large filling defect in the pelvis and the lower major calix, and a diagnosis of neoplasm was made. The pyelogram of the right kidney revealed a normal organ. At operation the left kidney was found to be polycystic; a normal right kidney was palpated transperitoneally, and the left kidney was removed on the presumption that there was a tumor in addition to the polycystic change. The filling defect was caused by a large cyst.

Wells contended that in these 2 cases in which the pyelogram was normal and there were no abnormal findings on transperitoneal palpa-

17. Wyler, J.: Experimenteller Beitrag zur Frage der tuberkulösen Bacillurie, Vorläufige Mitteilung, Ztschr. f. urol. Chir. u. Gynäk. **42**:157-163 (Feb.) 1936.

18. Kretschmer, H. L., and Hibbs, W. G.: Actinomycosis of the Kidney in Infancy and Childhood, J. Urol. **36**:123-138 (Aug.) 1936.

19. Wells, Charles: Polycystic and "Unilateral" Polycystic Kidney: A Review of the Literature and Two Cases, One with Intra-Cystic Papilloma, Brit. J. Urol. **8**:22-35 (March) 1936.

tion of the opposite kidney, the assumption is reasonable that the disease is unilateral. Time alone will tell whether the normal kidney was potentially polycystic. However, in predominantly unilateral disease, nephrectomy is indicated when symptoms arise on the diseased side which demand intervention.

Wells stated that in certain cases in which the pyelogram of the opposite kidney is normal and the kidney is normal to palpation transperitoneally at operation, a "clinical" diagnosis of unilateral disease can safely be made. Several postmortem examinations have disclosed true unilateral disease.

Extreme conservatism, because of the belief held by the majority that the disease is always bilateral, has excluded many patients from the benefits of a well planned operation. Wells stated that provided careful functional studies have been done (1) operations other than on the kidneys may be undertaken with little increased risk as contrasted with operations on the normal subject and (2) operations on, or for the removal of, one kidney can be undertaken (*a*) without undue risk if the function of the other kidney is good and (*b*) with considerable, but not prohibitive, risk in cases of extreme urgency, even when the function of the other kidney is poor.

The indications of extreme urgency are: (1) severe infections or injury, (2) severe lumbar pain and (3) suspicion that a malignant condition is present.

The operations which may be carried out on the kidney itself are as follows: (1) Rovsing's puncture, by which many cysts are broken down; (2) the excision of some of the larger cysts, which is not a really practical procedure; (3) partial decapsulation (Marion); (4) drainage of the pelvis and/or the perirenal tissue; (5) nephrectomy, and, for statistical purposes, (6) exploration of the kidney with no further procedure. Rovsing's puncture reduces the size of the kidney and furnishes relief from pain, but secondary nephrectomy is often called for, especially in cases in which infection is present.

Urinary Lithiasis.—Barney and Mintz [20] reviewed the work done at the Massachusetts General Hospital on the relation of the parathyroid glands to urinary lithiasis. Determinations of blood calcium and phosphorus were made on 288 of the 340 patients who had urinary lithiasis, observed in that institution in the years 1933 to 1935, inclusive. In this manner 12 (4.16 per cent) cases of hyperparathyroidism were discovered. This brings the number of parathyroid tumors to 29; 20 of these were associated with renal calculi. Of these 29 cases, skeletal lesions (osteitis fibrosa) alone were observed in 5, lesions of the urinary tract alone in 13 and combined urinary and skeletal lesions in 11.

20. Barney, J. D., and Mintz, E. R.: The Relation of the Parathyroid Glands to Urinary Lithiasis, Brit. J. Urol. **8**:36-44 (March) 1936.

In 8 cases of renal stone, in 6 of which the condition was bilateral, antemortem studies of the blood and postmortem studies of the parathyroid glands were made. The parathyroid glands were not diseased in any case, but the finding of normal amounts of calcium and phosphorus in the blood in the presence of normal parathyroid glands was confirmed. Because of the impression that renal calculosis in disease of the parathyroid glands is likely to be bilateral, 35 cases in which bilateral stones were present were carefully examined, and this assumption was not confirmed.

Special precautions must be taken to avoid contamination with calcium when taking blood for the determination of the calcium and phosphorus content, and the determination should be made only by a competent biochemist. More than 11 mg. of calcium per hundred cubic centimeters of blood and less than 3.5 mg. of phosphorus should arouse suspicion of parathyroid disease.

If there is only slight or moderate renal injury and no urgent necessity for removal of the stones, the parathyroid glands should be operated on first. Failure to correct the metabolic dysfunction first may result in reformation of the stones after their removal.

The readjustment of the calcium and phosphorus in the blood to normal amounts is rapid after removal of the parathyroid tumor. In Barney and Mintz' series of cases there has been no recurrence of stone, despite the fact that infection and obstruction persisted in a number of cases. However, the other important factors in the etiology of calculosis should not be neglected in the follow-up treatment. A careful dietary regimen should be planned; chemical examination of the blood and urine should be made frequently; the urine should be kept strongly acid, and roentgenograms of the urinary tract should be made from time to time.

Barney and Mintz concluded that no physical examination, especially if urinary lithiasis is present or suspected, is complete without a careful study of the calcium and the phosphorus content of the blood.

Pyelitis Cystica.—Hinman, Johnson and McCorkle [21] stated that pyelitis and ureteritis cystica are pathologic conditions of the mucous membranes of the pelvis and ureter secondary to an inflammatory process. Cystitis cystica is almost always an associated condition. The mechanism of production is probably that described as the "cell nest" theory of von Brunn. The present methods of urologic study of pyelitis and ureteritis permit a clinical diagnosis of the condition in many cases. Dilatation of the ends of the major calices with narrowing of the arms of the calix below and cystic dilatation at the ureteropelvic junction

21. Hinman, Frank; Johnson, C. M., and McCorkle, J. H.: Pyelitis and Ureteritis Cystica: Three Case Reports with Clinical Diagnosis, J. Urol. **35**:174-189 (Feb.) 1936.

(not true pyelectasis) are typical of pyelitis cystica. The peculiar mottling of the ureterogram, similar to bubbles of air in the ureter, is typical of ureteritis cystica.

Physiology.—Pisani [22] stated that the function of the kidneys is comprised of two distinct acts, namely, secretion and excretion. First, waste substances and varying amounts of water are filtered and secreted by the kidneys from the blood, and thus urine is formed. Second, the urine which has been formed is excreted through a system of communicating canals and cavities.

Urinary excretion is that physiologic function the purpose of which is to gather and evacuate the secreted urine. The apparatus which carries out this function starts at the apex of the calices, continues through the pelvic tract, the ureter, the bladder and the urethra and finishes at the external urethral meatus. A study of the pathologic changes of renal excretion involves consideration of all the urinary functional alterations that take place which disturb normal physiologic evacuation of the urine, from the calices through the pelvis and the ureter to the bladder.

If the renal excretory system can be divided into several segments (calices, pelvis and ureter) from an anatomic and topographic point of view, it physiologically and pathologically makes up one functional unit only; in pathologic conditions, any segmental alteration causes functional disturbance of all the apparatus.

Physiologically, the pyelo-ureteral system is equipped to carry out an important function of compensation in the changeable adaptations, which are ruled by the variations of secretory diuresis, and evacuation of the bladder. With a rapid increase of diuresis, or delayed evacuation of the bladder, it reacts with extra physiologic muscular movement and a lowered tonus; the object of this is to increase the capacity of the excretory ducts and the quantity of urine evacuated so as to keep an equilibrium between secretion and excretion. The pelvic cavity is the segment which contributes the most to this compensation by becoming dilated.

Any pathologic cause that undermines the functional integrity of the dynamic elements (muscular fibers, innervation centers and tracts) or hinders the free course of the urine in the inside of the excretory tracts becomes a factor in the lack of functional equilibrium. In these conditions the results may be different; the compensatory elements may succeed in restoring a normal function by doing away directly with the cause, they may keep up a relative equilibrium pending removal of

22. Pisani, G.: Pathologia della escrezione renale, Kong. internat. Gesellsch. f. Urol., 1936, pp. 380-472.

the cause or they may reach the state of total lack of compensation through a new primitive equilibrium obtained at the cost of greater functional activity.

The causes capable of producing a pathologic alteration of renal excretion are: (1) congenital malformations; (2) pathologic conditions of any kind, acquired or congenital and capable of contracting, occluding or compressing the caliber of the excretory ducts; (3) anatomic and functional lesions of the intrinsic or extrinsic muscles or nerves capable of stimulating, inhibiting, abolishing or in any way incoordinating the essential properties of tonus and motivity of the neuromuscular excretory system, and (4) congenital or acquired conditions which may influence the opening and closing of the ureteral outlets.

The causal anatomic and etiologic element can act pathogenically in causing a pathologic excretory lack of equilibrium only in two ways: (1) either as a mechanical irritating and transitory factor, capable of producing an exaggerated irritating dynamic reflex, or as an abnormal factor, in excess in the beginning and afterward in default, and (2) either as a first or as a second lesion factor of anatomic integrity of the neuromuscular system that rules renal excretion. In this case it is an essentially dynamic element. As the principal element of renal excretion is that of the peristaltic waves, it depends directly on the dynamic laws. The mechanical laws intervene only in special cases, by causing alterations that always end by having an echo in the dynamism of the pyelo-ureteral duct.

Fuchs [23] proved that the fornices of the calices of the kidney have a physiologic function. Rupture of the fornix and pyelovenous reflux are a pathologic event. Under physiologic conditions there is resorption through the fornix, not by rupture but by formation of small splits between the cells of the epithelium. Study of the ontogenesis reveals that the fornices have an important function. Reabsorption through the fornices is necessary to secure a proper balance between secretion and excretion of urine.

The morphologic changes the fornix undergoes in adapting its function to unusual demands is given as proof of the importance of the fornix.

Wildbolz and Walthard [24] examined 74 recently removed kidneys of human beings by the method of Warburg. They were able to measure

23. Fuchs, Felix: Die physiologische Rolle des Fornixapparates, Ztschr. f. urol. Chir. u. Gynäk. **42**:80-100 (Feb.) 1936.

24. Wildbolz, Hans, and Walthard, Bernhard: Die Beeinflussung der Funktion und des Stoffwechsels der Niere durch tuberkulöse und banale Infektion, Lithiasis, Harnstauung und primäre maligne Tumoren, Ztschr. f. urol. Chir. u. Gynäk. **42**:1-20 (Feb.) 1936.

the respiration, that is, the consumption of oxygen, by the surviving animal tissue.

Sixty of the kidneys were tuberculous; 11 were hydronephrotic, some of which were the site of pyelonephritis and lithiasis, and 3 were the site of primary malignant tumors. The kidneys were removed with the patients under ether anesthesia. The most normal sections, while still warm, were placed in Ringer's solution and examined at once.

The authors compared the renal function before operation with the microscopic changes found and the metabolism of the parts of the kidney examined. In cases of caseating tuberculosis of the kidney, renal function and the consumption of oxygen were comparatively parallel. In cases of early tuberculous involvement in which normal tissue could be examined that was removed at a distance from the tuberculous focus, the metabolism was normal. In cases in which caseation was advanced and in which renal function was extensively injured, leaving only small areas of normal tissue, the microscopically normal areas had a highly reduced metabolism.

Wildbolz and Walthard concluded from this that the damaging effect of the tuberculous toxins extended for only a short distance around the focus and that in cases of early tuberculous involvement the tissue that is at a distance from the focus remains untouched. Acute inflammatory processes increase the consumption of oxygen.

Conclusions could not be drawn from the 3 cases of malignant tumors, but in all 3 the consumption of oxygen of the normal parts of the kidney was normal or slightly increased.

Sympathectomy.—Gibson [25] concluded that renal sympathectomy produces no harmful effects on the kidney; it is surgically feasible either alone or in conjunction with other procedures, and in a number of conditions there are either relative or definite indications for its application.

Among the indications for renal sympathectomy are renal sympatheticotonia (spasm, atony, dyskinesia, hyperdynamic motility and adynamia), either alone or in association with definite organic changes (slight hydronephrosis, nephroptosis, painful chronic nephritis, painful adhesive perinephritis, essential hematuria, certain types of Bright's disease associated with oliguria and anuria, cases of unyielding reflex anuria and possibly certain cases of stone-forming diathesis).

Renal sympathectomy is recommended, in conjunction with other necessary surgical procedures, as an extraprecautionary measure to make doubly sure of complete relief in any case of proved renal pain in which careful investigation reveals little or no demonstrable pathologic change to explain the symptoms adequately.

25. Gibson, T. E.: The Present Status of Renal Sympathectomy, California & West. Med. **45**:10-13 (July) 1936.

Denervation.—Dambrin [26] expressed the belief that he was the first, in 1932, to envisage and carry out "total denervation" of the kidney, which included chemical sympathectomy of the renal pedicle and cortex after rapid denervation of the pedicle with the knife, and decapsulation. This total denervation frees the kidney by complete section of its nerves from the sympathetic centers and thereby prevents all vasoconstrictor action. It produces enormous vasodilatation. For a certain length of time the kidney becomes an organ controlled by its parasympathetic nervous system and no longer responds to the vasoconstrictor nerves, which predominate in the diseased kidney, nor does it react with any pain. Decapsulation alone and instrumental denervation alone are incomplete procedures. Dambrin supplemented these two procedures with *badigeonnage,* which is the application of Doppler's solution (a preparation of phenol) to both the decapsulated cortex and the renal pedicle.

Total denervation of the kidney is compatible with excellent secretory function of the organ. There is everything to indicate that intrarenal nerve centers exist which are adequate for the control of the phenomena of secretion. Since such centers have been discovered in the heart and intestine, it is the author's conviction that similar centers in the kidney will some day be brought to light. By suppressing the paths of conduction, this intervention acts on many a reflex anuria and has produced good results in nephralgia, hematuric nephritis and essential hypertension, in which the vasomotor factor was the most important.

Badigeonnage of the decapsulated kidney causes congestion of the gland and revitalization comparable to that which is known to occur in the testes and ovaries under this treatment. That it acts directly on the glomeruli and perhaps on the intrarenal nerve centers without doing the least injury to the normal formation of the kidney has been shown indisputably by numerous histologic sections. The association of these three procedures gives more intense effects than any kind of partial action.

The operation is simple and is done in four stages: (1) decapsulation, (2) denudation of the artery and section of five or six large nerves surrounding the pedicle (small fibers may be disregarded); (3) *badigeonnage* of the artery and cortex with a gauze tampon soaked in the phenol solution, a substance without injurious effects, and (4) nephropexy, by any suitable method. In cases of nephritis in which the capsule is stoutly adherent and in which severe perinephritis renders

26. Dambrin, Louis: "L'énervation totale" du rein ou "sympathectomie chimique du pédicule rénal et de la corticalité du rein après énervation rapide du pédicule au bistouri et décapsulation," J. d'urol. **41**:105-111 (Feb.) 1936.

decapsulation impossible, one may, if necessary, do simple *badigeonnage* without decapsulation. In this case the liquid acts on the nerves of the enveloping capsule and by destroying them prevents the vasoconstrictor action of the renocapsular anastomosis.

Indications for this treatment are found in painful conditions caused by slight hydronephrosis, compression of the kidney by the capsule, irritation of the renal plexus or neuritis and in certain cases of nephritis in which the normal cells of the kidney are only slightly involved and in which the majority of the disturbances are of a vasomotor nature. In cases of very acute nephritis, whether toxic or infectious, only mediocre results have been obtained. Chronic interstitial nephritis (Bright's disease) is hardly affected at all, but the operation is formally indicated in cases of hematuric nephritis. In cases of reflex anuria, total denervation should replace simple decapsulation. One of the best indications is found in cases of permanent hypertension, whether of glomerulonephritic or of nephro-angiosclerotic origin.

Dwarfism.—Kennedy [27] reviewed 7 cases of renal dwarfism and presented details of 5 of these cases. He emphasized the fact that the etiology, pathogenesis and relation of renal dwarfism to renal disease, hyperparathyroidism, other types of endocrinopathy and disturbed mineral metabolism are unknown. Clinically, the picture presented by these cases is that of retarded growth and skeletal development, changes in the roentgenographic appearance of the bones, impairment of renal function with resultant polyuria, polydipsia, albuminuria, azotemia and hyposthenuria, and hyperphosphatemia, with normal or abnormal concentrations of serum calcium. The changes in the skeleton which have been designated as renal rickets are sometimes striking features of the disease. Parsons has divided these changes into three types: (1) the atrophic type, in which the bones are fragile, atrophic and osteoporotic, with lines of cancellous tissue at the epiphysial ends of the diaphysis, a thin, atrophic cortex and fractures of the shaft; (2) the florid type, in which changes are characteristic of florid rickets, and (3) the woolly, stippled or honeycomb type, in which the epiphysial ends of the shaft are swollen and appear honeycombed, stippled or woolly. The ages of the patients ranged from 16 months to 8 years. Although in all the cases all the typical clinical findings were not present, retarded growth and development, impairment of renal function and some roentgenographic abnormalities were uniformly observed.

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27. Kennedy, R. L. J.: Renal Dwarfism, Proc. Staff Meet., Mayo Clin. **11**: 289-293 (May 6) 1936.

URETER

Diverticulum.—Brown [28] stated that diverticulum of the ureter is rare and that the cases reported appear to belong in several different categories, which have not as yet been clearly defined. Diverticulum of the ureter may be divided into three different types. Diverticulitis of the ureter is an acquired form of diverticulum, caused by some inflammatory lesion which weakens the wall of the ureter, and a "blow-out" forms at the point of weakening. This may or may not be accompanied by the formation of stones in the ureter. Ureterocele is a type of diverticulum occurring as a dilation of the intramural portion of the ureter just proximal to the orifice of the ureter in the bladder. The opening of the ureter is constricted, and the cystic mass projects into the cavity of the bladder. Congenital diverticulum occurring along the course of the ureter is the rarest form of this type of lesion. Only 8 cases have been reported in the literature. Brown reported a ninth one. The etiologic factor in the causation of this type of diverticulum is evidently failure of a portion of the ureteral bud to join with its functioning cap.

Ureterocele.—Lazarus [29] stated that cystic dilatation of the lower end of the ureter, or ureterocele, more frequently accompanies anomalous conditions of the ureter and particularly supernumerary ureters. Although several hypotheses have been advanced to explain this entity, the one which appears most logical is that the dilatation is due to some type of obstruction at the ureteral orifice, along with a weakening of the tissues around the submucosal end of the affected ureter.

Symptoms attributable to ureterocele are dependent on (1) obstruction of one ureter in the event the cyst is confined to one meatus or of both ureters when the cyst is bilateral or obstructs the vesical neck and (2) cystitis.

The diagnosis of ureterocele is definitely made by cystoscopy, but it can be strongly suspected on the basis of the roentgenographic picture. The suggestive findings by excretory pyelography are: (1) dilatation of the lower 2 to 4 inches (5 to 10 cm.) of the ureter, (2) bulbous dilatation of the vesical end of the ureter and (3) a negative shadow or defect in the cystogram in the region of the bulbous end of the affected ureter.

The treatment of cystic dilatation of the lower end of the ureter consists of (1) transurethral methods, (2) intravesical methods and

28. Brown, Alfred: Ureteral Diverticula, West. J. Surg. **44**:270-278 (May) 1936.

29. Lazarus, J. A.: Cystic Dilatation of the Lower End of the Ureter: Special Reference to the Transurethral Treatment with the High Frequency Cutting Current; Report of Two Cases, J. Urol. **36**:139-149 (Aug.) 1936.

(3) nephrectomy when the kidney is destroyed. The procedure employed by the author was the use of the high frequency cutting current passed through a cystoscope by which the cyst was widely opened. Subsequent treatment consists of repeated dilation of the newly established ureteral orifice.

Lazarus reported 2 cases of cystic dilatation of the lower end of the ureter associated with reduplication of the pelvis, which have been completely relieved by the transurethral use of the high frequency cutting current.

Rhodes [30] reported 13 cases of ureterocele. Congenital stenosis of the orifice of the ureter is the most likely explanation for the lesion. Symptoms are mainly attributable to obstruction and infection. Diagnosis is made by cystoscopy and occasionally on the basis of the roentgenographic picture. The method of treatment advocated is the transurethral incision of the cyst by means of the diathermy current.

Changes in Pregnancy.—Traut and McLane [31] stated that the normal ureter of the nonpregnant woman is possessed of rhythmic peristaltic activity which can be measured and recorded. This rhythmic peristaltic activity is definitely altered in varying degrees by pregnancy in the majority of the patients studied. There is diminished amplitude of the peristaltic wave; this commences in the third month of pregnancy and reaches its peak during the seventh and eighth months. After the fifth month the number of patients who had diminished ureteral response exceeded those who had normal activity. During the last month of pregnancy there seemed to be a definite return of muscular irritability, as expressed by the measurement of peristalsis and responses to stimulation. This diminished peristaltic activity of the ureters seen in pregnancy cannot be explained on the basis of dilatation. Dilatation of the ureters during pregnancy is probably mainly dependent on atony of the ureters. Traut and McLane expressed the belief that the etiology of this ureteral atony observed during pregnancy is not dependent on any mechanical factor but on some, as yet unexplained, chemical basis.

Stone.—Shaw [32] reported 4 cases in which vaginal ureterolithotomy had been performed and which illustrate some of the advantages of this procedure. In 2 patients the operation seemed to be imperative, as removal of the calculus by any other approach appeared impossible at the time. The accidental production of vesicovaginal fistula in his

30. Rhodes, J. S.: The Clinical Importance of Ureterocele, J. Urol. **35**:300-308 (March) 1936.

31. Traut, H. F., and McLane, C. M.: Physiological Changes in the Ureter Associated with Pregnancy, Surg., Gynec. & Obst. **62**:65-72 (Jan.) 1936.

32. Shaw, E. C.: Vaginal Ureterolithotomy, J. Urol. **35**:289-297 (March) 1936.

first case revealed a possible operative complication. If the relationship of the base of the bladder, uterine cervix and ureter is borne in mind, this accident should never occur. The bladder can be readily avoided by inclining the dissecting finger laterally and posteriorly and approaching the ureter on its lateral and posterior aspect. A wound made in the ureter by this approach should be no more difficult to heal than one made in the more orthodox manner. The healing time in Shaw's cases was probably reduced by the employment of the indwelling ureteral catheter—a point, however, which can be settled only by more experience. Differences of opinion may arise as to the selection of cases for the employment of vaginal ureterolithotomy. Impacted stones, readily palpable on vaginal examination, fall into this group. Shaw has not used the operation for a calculus that was not palpable on vaginal examination, but it is probable that calculi so small or so high as not to be palpable, but demonstrated in the lower part of the ureter in the roentgenogram and fixed with a ureteral catheter, may be handled by this approach. The failure of an attempt to remove urinary calculus by the vaginal route would be of no particular danger to the patient, and it might be tried even in doubtful cases before abdominal operation is employed. The advantages of vaginal ureterolithotomy are that it is a comparatively simple method of removing a stone from a site which is often difficult to approach by other methods; it affords dependent drainage in case of leakage; it avoids an external incision, and it shortens the period of convalescence.

Tumor.—Jeck [33] reported a case of bilateral metastatic carcinoma of the ureters, which was probably true metastasis from a primary focus in the sigmoid colon, causing obstructive anuria. He also reported a case of adenocarcinoma of the kidney in which the diagnosis was made clinically and the kidney removed. The patient died as a result of a concealed hemorrhage, and necropsy revealed an adenocarcinoma of the opposite kidney, which was not recognized preoperatively.

Bilateral tumors of the ureter have received little or no attention clinically. It would seem, however, that anuria attributable to obstruction caused by bilateral tumor of the ureters, although rare, is sufficiently significant to warrant its consideration, especially in cases of obstructive anuria not caused by stone. Jeck's other case emphasized the fact that bilateral tumor of the kidneys may exist oftener than is supposed. More attention should be directed to the supposedly sound kidney in eliminating the possibility of malignant disease.

33. Jeck, H. S.: Bilateral Malignant Lesions of the Upper Urinary Tract: Case Reports, J. Urol. **35**:206-212 (Feb.) 1936.

Trauma.—Hryntschak [34] opposed the widespread belief that a ureter that has been sectioned transversely cannot resume its normal function. After reviewing the literature both on animal experimentation and on clinical work, he described his own experiments, indicating his results in the healing of the ureter after resection. He found that the resumption of normal function after transverse section of a ureter is physiologically possible. Complete restitution of nonstriated mucular fibers does not occur. The nerve impulses probably pass through a few regenerative muscular fibers that could be found in most postoperative scars.

Hryntschak expressed the belief that the two principal needs for healing of a transverse cut in the ureter are temporary diversion of the urine through nephrostomy, pyelostomy or ureterostomy and the splinting of the injured ureter with a ureteral catheter.

Anomaly.—Deming [35] stated that ectopic ureters of the vagina produce uniform symptoms of vaginal dripping of urine which exists with normal urination. The opening for this anomalous ureter is on the anterior wall of the vagina near the midline between the hymen and the cervix. The right side is the more often involved, and the ureter always extends to the upper pole of the kidney. The kidney attached to the ectopic ureter of the vagina is of practically no functional value and is prone to infection. Intravenous injections of skiodan may not be of value in the diagnosis. No attempt should be made to conserve such ureters and kidneys. Heminephrectomy may be done if vessels are distinct to each kidney. If infection is present, complete nephroureterectomy is indicated. Diagnosis should be made in the first decade of life. Total ureterectomy affords a simple method of treatment when infection has not taken place.

Crenshaw and Buchtel [36] reported 7 cases of ectopic ureter with an extravesical orifice. They stated that the choice of surgical procedure depended on the conditions in the individual case, namely, the situation of the ectopic ureteral orifice, the presence or absence of single or supernumerary ureters, the presence or absence of infection or pathologic changes in any segment of either kidney or ureter, the function of all segments of both kidneys, the difficulty of surgical renal approach and the distribution of the vascular supply to the two segments. Various surgical procedures may be employed that are suitable to the individual case. The ectopic ureter may be ligated either through the vagina or

34. Hryntschak, T.: Zur Histologie und Physiologie des querdurchtrennten Harnleiters, Ztschr. f. urol. Chir. u. Gynäk. **42**:268-291 (Aug.) 1936.

35. Deming, C. L.: Ectopic Vaginal Ureter, Surg., Gynec. & Obst. **62**:843-851 (May) 1936.

36. Crenshaw, J. L., and Buchtel, H. A.: Ectopic Ureter with Extravesical Orifice, J. Urol. **35**:190-203 (Feb.) 1936.

at a point above the bladder. In 2 of their cases the ureter was ligated; 1 patient had a stormy convalescence; when 68 years of age she reported that she was well but had a cystic mass in the same side of the abdomen. The second patient recovered only after the drainage of a cystic kidney. An aberrant ureter may be transplanted into the bladder either through the vagina or transabdominally. In 2 of the cases this procedure was carried out transabdominally. One of the patients had a single aberrant ureter and had a satisfactory functioning and symptomless kidney eleven years after operation. The other patient had a small, uninfected upper segment and was perfectly well, with no change in function, ten months after operation. Heminephrectomy has its technical difficulties and may be precluded by inability to elevate the kidney or by the vascular distribution. In 1 case results were satisfactory after heminephrectomy. Nephrectomy may be indicated when both renal segments are pathologic or when other procedures fail, if the remaining kidney is normal. In 1 of the cases nephrectomy was performed with satisfactory results. Anastomosis, pelvis to pelvis, ureter to ureter or ureter to pelvis may be used. In suitable cases this should give good results and is a satisfactory method when other operations are not possible. An opening may be established between the ureter and the bladder by a plastic operation through the vagina, by cystotomy or by cauterization through the cystoscope.

(To be concluded)